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THE OCTOBER SCIENTIFIC MONTHLY

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THE SCIENTIFIC MONTHLY

OCTOBER, 1935

THE BEGINNINGS OF TIME-MEASUREMENT AND THE ORIGINS OF OUR CALENDAR[1]

By Professor JAMES HENRY BREASTED

DIRECTOR OF THE ORIENTAL INSTITUTE OF THE UNIVERSITY OF CHICAGO

Introduction

The processes of matter seem to be the most tangible yardstick which we can apply to that mysterious flow which we call time. But the processes of matter are sublimely indifferent to the insignificant time frontiers erected by man's petty scientific terminology. As if in ridicule of such barriers raised by the children of time, the operations of the universe cross and recross the tiny areas which man has staked out. We are like some frontiersman in the night holding up a torch over a dark stream and imagining that the circle of its hurrying current revealed by the torchlight is all there is to the stream, while there may be Great Lakes above and a thundering Niagara below.

In this brief discussion of a vast subject let me make it clear that I am not dealing with any philosophical conceptions of time or its nature. I am merely endeavoring to present a sketch of some historical aspects of man's notions of time, by a study of the earliest sources of information available, with the purpose of disclosing especially the earliest known methods of time-measurement and the origins of our calendar.

[1] Lecture before New York University, given on May 16, 1935, The James Arthur Annual Lectureship on "Time and its Mysteries."

Discontinuous Time

Modern science has so long been dealing with time as something in *continuous* flow that we accept this conception as a matter of course. This notion of time, however, as uninterrupted duration, in ceaseless, ever-continuing flow, was the final result of ages of human effort to deal with it, and did not arise until an advanced stage of civilization. An American Indian, before he was touched by civilization, would have told you that he was "fifty winters" old, or a younger native would have said that his age was "twenty snows." He thus measured time in disconnected fragments, and throughout the globe that has been the only conception of time discernible by primitive men. Some of these time fragments are fixed seasons in the early man's folk-calendar. Among certain Swedish peasants even at the present day a birthday may fall at the "rye harvest" or at the "potato harvest." A Palestinian peasant may fix the date when a note falls due, not at the end of a continuous series of months, but at the next ripening of the fakûs, a kind of cucumber. Convenient fractions of time may be designated as so many *nights*. In English we still have in common use the period "fortnight," an abbreviation of "fourteen nights." Somewhat less

common is the term, "sennight," for "seven nights." This use of nights as a series of disconnected time fragments, still current in English, is of course a survival from primitive usage, like our own North American Indian's measurement of a short journey to a mountain visible on the horizon as "so many sleeps." For a longer journey, however, to the sea far behind the mountain, the Indian would say, "so many moons."

For ages the primitive man had no conception of time, but merely of a series of disconnected units of time, what modern investigation calls "discontinuous time." The short period during which the moon disappears is so brief that a succession of moons was not broken up into disjointed links, and a series of moons therefore gave the early man his longest uninterrupted flow of time. The moon thus became the first continuous time-measurer for periods of time within the year. Almost everywhere the primitive woman knows that, ten moons (that is about nine months) after her periods have stopped, her child will be born. That measurement of the length of pregnancy is one of the oldest continuous time units on record; but it fell short of a year by almost three more moons. The process of linking together the disconnected time units to form a year and thus build up a calendar was an achievement belonging to an advanced stage of civilization.

The Luni-Solar Year

The cycle which we call a year was of course early observed by primitive man. The changing phases of the face of nature could not fail to attract his attention nor could he fail to notice that certain of these phases recurred with great regularity. On some of them he was dependent for sustenance and life itself. Every day there impinged upon him some aspect of the natural world, of sky and earth in a sweepingly wide range, from the far-off celestial bodies above to the changing life below, of trees and plants, cattle and birds and insects, and the sacred observances of man himself, based to no small extent upon occurrences in the natural world. While he had noted these recurrences for ages, the early man made no effort to determine the number of days in the cycle between any one of these events and its next recurrence, and thus to establish the length of the year. Simple as it seems to us, the conception of the year, the length of its duration and the mere arithmetic of counting the days which it occupied were far beyond human powers at first. What he did at first observe, however, was that the seasons recurred after an interval of about twelve moons. For ages his ideas of the length of year remained wholly vague as a group of roughly twelve moons. Gradually each moon month gained a name drawn from some event in the life of plants and animals, or some sacred observance of man himself connected with such an occurrence in nature.

The effort to fit the series of moon months into the cycle of the year was never successful. Throughout the ancient world, especially in western Asia and Greece, man struggled with the practical problem of the incommensurability of the length of the year and the moon month. We are accustomed to say that the Greeks were the first people to gain complete intellectual emancipation, but in the measurement of time their men of science suffered under such complete intellectual subjection to inherited tradition in the use of the moon month as a subdivision of the year that they continued to use a year divided into months, of which there were twelve and a fraction in each year. They resorted to elaborate devices for making a term of years equal to a given number of integral moon months. They devised a cycle of eight years with three intercalated

moon months or, more accurately, of nineteen years with seven intercalated moon months. The engineer Meton, who adopted the nineteen-year cycle from acquaintance with Babylonian astronomy, knew well enough that his elaborate cyclic scheme did not match exactly with the observed new moons. In view of this fact it is most extraordinary that the Greeks never possessed the intellectual emancipation to reject the moon entirely from their calendar and adopt a conventional month dictated by social needs. They knew of the Egyptian calendar, and in the middle of the fifth century B.C. Herodotus praises it, evidently under the impression that its year of 365 days was correct. But the Greeks had inherited their lunar calendar from Babylonia, and it was so firmly entrenched in their life, beliefs and customs that they were never able to cast it off.

From the earliest times the lunar month dominated the calendar of western Asia, where it arose at least as early as the fourth thousand years B.C. under the leadership of Babylonian civilization. The Babylonian kings at first adopted an erratic method of intercalated months inserted at irregular intervals, by royal command whenever the king noticed, as Hammurabi says in one of his letters, that "the year hath a deficiency." He then ordered the insertion of an intercalary month. It was not until 528 B.C. under Persian sovereignty that Babylonia adopted a fixed lunar cycle for the insertion of intercalated months at regular intervals. It was this cyclic system which was introduced from Babylonia by the Greeks. At the very time when the Greeks were thus fastening upon themselves the intolerable inconvenience of a lunar calendar they might have observed that Darius the Great, the ablest administrator of the ancient world, had introduced into the Persian Empire the Egyptian calendar, which disregarded the moon month. The long-established habits of the Western Asiatic peoples, however, and especially the eventual triumph of Islam, resulted in the universal restoration of the lunar calendar. The disharmony between the lunar and the solar year was carried to the absurdest conceivable extreme by Mohammed, who was so densely ignorant of the nature of the calendrical problem that in the Koran he actually forbade the insertion of intercalary months. The so-called "lunar year" of 354 days, being eleven days shorter than the solar year, revolves entirely around the solar year in a little over thirty-three years, that is, about three times in every century. A monthly observance like Ramadhân, the month of fasting, if it is now in June, will be in April six years from now. It is now (1935) 1,313 years since the Hijra, or the Hegira, the beginning of the Moslem era, but each of our centuries contains over 103 of the shorter Moslem lunar years. In 1,313 of our Gregorian years there are about forty-one more Moslem years, so that the Moslem era of the Hijra is now in the year 1354 (that is, 1,313 plus forty-one).

The authorities of the Jewish church in the Orient avoided such absurdity, and employed intercalation to keep their lunar calendar at least roughly within the framework of the solar year. All western Asia therefore still continues to suffer under the inconvenience of the most primitive form of time-measurement, the lunar calendar.

The Stellar Year

The Egyptians were the only ancient people who clearly recognized the cause of that inconvenience and possessed the courage and intellectual freedom to remove it. The total incommensurability of the solar or stellar year and the so-called "lunar year" could be discovered only after determination of the length of the solar or stellar year, and recognition

of the fact that there is no such thing as a "lunar year."

The determination of the length of the year, together with the discovery that it had a fixed length, was a long slow process lying far back in prehistoric ages. As we shall see, it is an extraordinary fact that it was not the sun which first furnished early man with the length of the year. Other natural phenomena much more intimately within his circle of observation must first have revealed to him the beginning of another annual cycle. The beginning of the annual run of salmon, the blossoming of certain plants or, after the introduction of agriculture, the successive tasks of cultivation might mark the years. The peasants of Palestine call the years so many "threshing floors"; the Arabs of Lower Iraq count the years by "date harvests"; in the East Indian Archipelago the years are counted by "rice harvests." The conception of a year thus arose gradually. On the East Indian Island of Bali the two monsoon seasons are each made up of a list of months which have the same names and are therefore identical for the two halves of the year. This fact shows us that the two seasons were separated from each other and the conception of the complete year cycle had not yet arisen. The process of uniting the seasons into a year was therefore a slow and gradual one. At first, as may still be observed among some surviving primitive peoples, there arose a list of moon months which did not fill the entire year. After those months were past, before the beginning of a new year, there followed a period of indifferent length, completing the old year. This intermediate period of varying and indifferent length served to adjust the inequality between the solar year and any number of integral lunar months and brought the months into rough correspondence with the solar year. Eventually there arose a list of lunar months, twelve to thirteen in number, which were thought to fill the entire year. There is, however, no equivalence between an arbitrary series of lunar months and a solar or stellar year. Hence there really is no such thing as a "lunar year," and Mohammed's year of 354 days is a creation which corresponds to nothing in nature. Historically, the lunar month has been useful as first suggesting a convenient series of twelve subdivisions of the year, but beyond that fact it has caused endless confusion and complication throughout human history.

The lunar month of course contributed nothing to the determination of the length of the year, and curiously enough the sun, the other great luminary, did not first enable man to discover the year and determine its length. While the sun's apparent revolutions shift their positions from season to season they nevertheless go on in an unbroken series with no beginning and no end. The sun's apparent motions therefore did not at first suggest the year cycle. It is quite evident that primitive men had very early begun to observe the stars and to notice the reappearance of a prominent star or group of stars after it had been invisible for a time. Such a reappearance was an event which cut sharply into the sequence of events in the stellar sky, and easily came to mark the beginning of the year. In several regions of South America the word for Pleiades is the same as the word for year. In the eighth century B.C. Hesiod places his agricultural program in the calendar by observing the return of the Pleiades in May. If the Greeks had only continued to build up their calendar on this stellar observation, they might have saved themselves centuries of difficulty and complication with their inherited Babylonian lunar calendar.

In prehistoric ages, many thousands of years ago, the dwellers along the Nile, the greatest river known to ancient man,

very naturally began their year with the beginning of the annual rise of the vast river, as the most important terrestrial phenomenon of which they knew and also the source of fertility on which an agricultural people depended for their very life. The four-month season of the inundation, which fructified the fields, was followed by another four-month season of planting and cultivation, and a third and final four-month season of harvest. This year of three four-month seasons was obviously one which arose out of the life of an agricultural people. It was essentially an agricultural folk-calendar, and its months were obviously moon-months in the beginning and doubtless continued to be so for thousands of years.

But, like primitive man everywhere, these earliest known agricultural peasants along the Nile had begun at a very remote date to scan the heavens and observe the stars, probably some thousands of years before Hesiod was doing the same in the eighth century B.C. There is probably no other country in which Sirius, the Dog Star, the brightest of the so-called fixed stars, is such a brilliant and noticeable spectacle in the evening sky. In the latitude of Lower Egypt Sirius rises about four minutes earlier every day. Every fifteen days he rises about an hour earlier, so that eventually he rises in full daylight, when he is of course entirely invisible. After a period of some months of invisibility, this brilliant and beautiful star suddenly reappears on the eastern horizon at sunrise. This "heliacal" rising of Sirius, as it is called, is a noticeable and sharply defined event. By a remarkable coincidence this heliacal rising occurs very near the time of the beginning of the inundation. In antiquity this date was the nineteenth of July. By a lucky accident, the beginning of the year at the advent of the inundation in the enormously ancient peasant calendar was thus fixed at the moment of an important astronomical event. The basis of the calendar which was to become that of the civilized world was therefore a stellar, not a solar year.

The 360-Day Year

It is important to notice that the earliest observances of the heliacal rising of Sirius must have been very primitive in character, as we shall later illustrate. Persistent dust storms, such as we experience to-day, desert fogs and mists or sometimes storm clouds must have made the determination of the exact day when Sirius reappeared on the eastern horizon not a little uncertain. It is certain that the length of the stellar year as measured by successive sunrise reappearances of Sirius was at first roughly established by the Egyptians as 360 days. As early as the fourth thousand-years B.C., that is, well back of 3000 B.C. we find this 360-day year divided into thirty-six decads of ten days each, for grouping the constellations along the celestial equator. This appearance of a circle of thirty-six decads in the fourth millennium B.C. is highly significant. It is certainly the oldest appearance of a circle of 360 divisions. The Sumerian sexagesimal system, in which sixty appears as a numerical unit (called *šuššu*), is without doubt enormously old; and in all probability arose from the length of the year—360 days—by dividing it into six parts. It seems probable, as concluded by Zimmern, that *šuššu*, the Babylonian word for sixty, means "one sixth." In both Babylonia and Egypt the convenient and basic number (360), of fundamental importance in the division of the circle and therefore in geography, astronomy and time-measurement, had its origin in the number of days in the year in the earliest known form of the calendar. While its use seems to be older in Egypt than in Babylonia, there is no way to determine with

certainty that we owe it exclusively to either of these two countries. A common origin older than either is possible.

The 365-Day Year

The Egyptians found their primitive 360-day year very convenient in business and social life, and it therefore survived far down into the historic age; but as their observations of the heliacal rising of Sirius accumulated, they finally discovered that the year, as they thought, contained 365 days. We are in a position to determine the date when they took administrative action to make this discovery of the approximate length of the year practically effective. In the year 4236 B.C., as determined by Borchardt, some now unknown ruler of prehistoric Egypt, without doubt residing in Heliopolis, introduced a calendar year of 365 days. It began with the heliacal rising of Sirius, that is, on the nineteenth of July. This calendar contained the three old agricultural peasant seasons: the inundation, the cultivation and the harvest, each season containing four months. The epoch-making importance of this calendar lies in the fact that these twelve months were entirely divorced from any connection with the moon, so that the deviser of the calendar could make each month thirty days long. By the addition of five feast days at the end of the year, this year of twelve thirty-day months or 360 days became the earliest known and practically convenient calendar of 365 days.

Earliest Fixed Date in History

The only celestial phenomenon to which any attention was paid in devising this calendar was the establishment of the beginning of the year at the first heliacal rising of Sirius. In other words, the mind that devised this calendar put social and economic needs first and divorced the calendar from celestial processes. It is of the greatest interest to observe that this calendar inevitably soon parted company with Sirius, for, owing to the fact that the stellar year is about a quarter of a day longer than 365 days, Sirius rose a day late, every four years; that is, at the end of the fourth year after the introduction of the calendar he rose on the second day of the New Year or one day late; at the end of eight years two days late; that is, on the third day of the year; at the end of twelve years three days late; that is, on the fourth day of the year; and so on to the end of the year. The calendar-makers did not at first observe this discrepancy, and when they finally did become aware of it, they held to the supremacy of social considerations, and made no attempt to shift the calendar back into harmony with Sirius. Eventually, therefore, in four times 365 years, that is in 1,460 years, the Egyptian calendar revolved entirely around the celestial year. A remark by Censorinus informs us that in the year A.D. 139, Sirius rose on New Year's day, that is, New Year's day in the civil calendar of Egypt once more coincided with the heliacal rising of Sirius. It is easy to compute that the next earlier coincidence of this kind must have occurred in 1318 B.C., the next earlier in 2776, and a still earlier one in 4236 B.C. Archeological considerations forbid us to suppose that we may push back still another such period of 1,460 years. We may therefore conclude that the civil calendar of Egypt was introduced in 4236 B.C.

This date, near the middle of the forty-third century B.C., is not only the earliest fixed date in history, but also the earliest date in the intellectual history of mankind. It has been well said that "the Egyptian calendar is the greatest intellectual fact in the history of time reckoning,"[2] but it is far more than that. For the introduction of this calendar was

[2] Nilsson, "Primitive Time Reckoning," p. 280.

an intellectual feat, marking the dawn of a recognition of the supremacy of social requirements. As we have already remarked above, in divorcing this new calendar from the processes of nature, the Egyptians were recognizing for the first time a world of social needs which they placed first. It is to-day the earliest known such recognition, and the earliest dated intellectual event in human history. It ushered in the great epoch, which was in full development after 4000 B.C., when the Egyptians discerned that their once purely nature-gods, who had originally been only personifications of natural forces and natural phenomena, like the Sun-god Re, or the Vegetation-god Osiris, were gradually shifted from a world of natural processes to be arbiters in a newly discerned social arena, where moral forces were emerging. The calendar was thus the beginning of a great movement in human life which carried over the thought of man from the world of nature to the world of human life.

Egyptian Source of European Calendar

This remarkable calendar remained the exclusive possession of the Egyptians for over thirty-five hundred years after its introduction. The effort of Darius the Great to introduce it into Western Asia late in the sixth century B.C. proved unsuccessful. The Greeks, as we have seen, wasted their scientific gifts in adding one futile refinement after another to the hopelessly inconvenient and complicated Babylonian lunar calendar. Nearly four and a half centuries after the fruitless attempt of Darius, another great administrative genius gave Europe for the first time a sane calendar. In 46 B.C. Julius Caesar introduced into the Roman Empire the Egyptian calendar, with one important modification. He provided for the addition of one day to the year of 365 days once in every four years. The history of this important innovation is interesting.

The first knowledge of a year of 365 days was brought to Europe by Thales, the Ionian philosopher, who learned of it on a visit in Egypt. Curiously enough, Herodotus also learned of it there and praises it as a perfect solution of the complications due to the incommensurability of moon-month and year. Neither Thales nor Herodotus seems to have known that the year of 365 days was too short. It is obvious that the Egyptians early observed the rate at which the heliacal rise of Sirius diverged from the beginning of the calendar in their civil year, revealing to them that their 365-day year was a quarter of a day short. The extraordinary achievements of the Babylonian astronomers in the Chaldean and Persian periods included a computation of the length of the solar year by Nabu-rimannu, or Naburianos, as the Greeks called him. Not long before 500 B.C. this great astronomer calculated the length of the solar year as 365 days, six hours, fifteen minutes and forty-one seconds—a result which is only twenty-six minutes and fifty-five seconds too long. This is the earliest known close approximation to the length of the solar year.

For over a century and a half no one seems to have made any practical application of this new knowledge. It was not until the third century B.C. that the Egyptians made an effort to correct the error in the length of the year. We still possess the granite stela of Ptolemy Euergetes I, bearing his decree, dated in the year 238 B.C., which commanded that every fourth year should be one of 366 days. But the Egyptian people obstinately refused to conform to this decree, and the correction in the calendar never became effective.

In 380 B.C. the able Greek astronomer and mathematician Eudoxus visited Egypt and there learned the fact that the year was really about 365¼ days long. Then for the first time this fact became common knowledge in Europe. Some two centuries later, that is, early in the

second century B.C., the great Greek astronomer Hipparchus announced that 365¼ days was in error, that is, it was too long by one three-hundredth of a day. This error was unknown to Caesar, and we all know that for this reason in March, 1582, the Julian calendar was superseded by that of Pope Gregory.

It is evident, however, that Julius Caesar brought to Europe for the first time a sane calendar system of twelve thirty-day months. If jealous Roman emperors and other scientifically ignorant meddlers had not utterly disfigured the Egyptian calendar, we would not be calling the ninth month September (with the numeral seven), the tenth month October (with the numeral eight), the eleventh month November (with the numeral nine) and the twelfth month December (with the numeral ten)! Nor would our young people be obliged to learn and repeat a verse of poetry in order to find out how many days there are in a month.

The Week

With the introduction of the Egyptian calendar time became something in which *human* processes were, so to say, systematically staked off into annual stages and substages. These subdivisions of a calendar, particularly the shorter ones, arise only at an advanced stage of social development. The origin of the month was of course due to a celestial phenomenon, but that of the week was in origin purely human and social. A market week of three, four, five, six, eight and ten days is a calendar division of purely secular origin. It is found over practically the entire globe, where civilization has advanced sufficiently to possess arts and crafts, with exchange and commerce of a primitive kind. It is quite commonly a *rest* day on which work is forbidden. There is a universal connection between market day and religion. Among some peoples, as among the Hebrews, the religious significance of the day predominates, and the feature of rest becomes a religious mandate. For our subject, the week, whatever its origin or significance, is of slight importance, for the week has played practically no part in time-measurement.

The Day

For many reasons, which are too obvious to need enumeration, the smaller subdivision, the day, has always been of fundamental importance in the measurement of time. It is extraordinary that among the various peoples there should be such wide diversity in the understanding of just what a day is. Modern astronomers consider a day as beginning at midday and therefore lasting from midday to midday. The peoples having a lunar calendar conceive the day as lasting from evening to evening; while in modern life the day begins at midnight and lasts from midnight to midnight, a point of practical convenience as marking the transition from one day to the next, and ignoring the night. This conception of a twenty-four-hour day is not even yet in our railroad time-tables. We really have two periods of twelve hours each, very inconveniently distinguished in our time-tables by leaded or black-faced type suggesting darkness at *midday*, which we sagaciously shift to light-faced type, suggesting daylight at *midnight!* The modern languages possess no word for the twenty-four-hour day. Only the ancient Greeks seem to have possessed such a word in their convenient *νυχθήμερον*. The Egyptians began the day at dawn, which seems the natural thing for an originally peasant people to do. The practise of beginning the day at dawn was adopted by Europe at an early date, and continued down into medieval times. It was the introduction of the striking clock, in the fourteenth century of our era, which shifted the beginning of the day to midnight.

There was as much diversity in the *length* of the day as in the time of its beginning. In view of the varying length of the *daylight*-day no one finds anything strange about a flexible or elastic day. It is in the subdivisions of the day that we have come to expect constant length. Division of the day into hours is unknown to primitive peoples. The Greeks and Romans in the West and the Chinese in the East had originally no hour divisions of the day, which they all received from the Near East. The Greeks were accustomed to identify times of day by such cumbrous devices as "the time of full market," which was the middle of the forenoon. Subdivision of the daylight-day into twelve parts was introduced into Egyptian life at a very early date. We find it in the Pyramid Texts, and this means that it was practised in the fourth millennium B.C., that is, before 3000 and possibly as early as 3500 B.C. The Egyptian was interested in a convenient division of his day into twelve parts, but he was not concerned that these twelve parts should be of constant length. The reason for this probably lay in his early timepieces, as we shall see. The Babylonians also possessed a subdivision of the day at an early date, but it divided the daylight-day into six parts, and the night into six more. The modern habit of translating the Babylonian term *bêru* (formerly read *kasbu*) for this part by "double hour" is of course very misleading, if not entirely incorrect.

The Earliest Timepieces

Sun-Clocks

What type of time-measuring devices the Egyptians at first employed we do not know. The earliest such devices that have survived in Egypt date from the fifteenth century B.C. They were of two kinds and measured time either by the observation of celestial processes or by the employment of physical processes under artificially arranged terrestrial conditions. The celestial processes employed for time-measurement were the movements of the sun and the stars. In a country as nearly cloudless as Egypt the observation of the sun was a valuable means of determining time. The Egyptians therefore devised the earliest known sun-clock. In its oldest form it was an instrument shaped like a T-square laid down horizontally. The cross-head of the T-square was laid toward the east in the forenoon, and was sufficiently thick to form a barrier casting a shadow along the much longer stem, which was graduated with marks for six hours. At dawn the shadow of the cross-head cast westward by the sun just clearing the eastern horizon covered the whole length of the graduated scale out to the mark of the first hour at the end. As the sun climbed the eastern sky the shadow shortened until at noon it disappeared at the mark of the sixth hour. The instrument was then turned around with the cross-head of the T-square toward the west, so that the lengthening shadow cast by the afternoon sun marched back along the hour marks to the twelfth, identical with the first hour at the end of the scale.

Such a system of determining time by measuring the length of the shadow cast by the sun was of course continually subject to alteration caused by the seasonal changes in the position of the sun. At first these Egyptian sun-clocks were fitted to the length of the day at the equinoxes and were not correct at any other season. It would have required some generations of experience in instrument making to have enabled even the supreme skill of the Egyptian craftsmen to produce a shadow clock of this type, which would have indicated correct time.

The sun-clock makers tried to adapt their instruments to seasonal changes by using a *series* of hour scales, eventually *seven* in number. This showed progress

and improvement; but such a sun-clock was not an accurate timepiece.

Moreover, the Egyptian did not yet know enough of the motions of the earth and sun nor of the mathematics involved to discern the underlying principles which should have governed the construction of his sun-clock, and especially the arrangement of the hour scale for the different times of day and for the changing seasons of the year. He further improved his clock by employing only a narrow beam of sunlight and shortening the graduated scale by raising it to an oblique angle of some forty-five degrees above horizontal. While improving the accuracy of the device, these changes also made it small enough to be portable. It was indeed the earliest known portable timepiece. It was equipped with a plummet so that it might be kept in the plane of the horizon; but little could be claimed for its accuracy. The great Egyptian conqueror Thutmose III refers to the hour indicated by the sun's shadow at a critical moment while on his first campaign in Asia. It must have been, therefore, that he carried with him into Asia some form of sun-clock. It is probably only a coincidence that the oldest sun-clock we possess bears the name of this king (fifteenth century B.C.).

Another form of sun-clock employed the *direction* of the sun's shadow, rather than its length. Lines diverging from a center were marked on a plane surface, which might be either vertical or horizontal, and these enabled the observer to determine the different hours, which were marked next to the lines. This form of instrument was simply a sundial, and evidently the ancestor of our own sundials. Again the Egyptian makers did not understand the rather complicated problems involved in making such a device indicate time accurately. It is interesting to note that one of these Egyptian sundials bearing the name of the Pharaoh Merneptah of the thirteenth century B.C. has been discovered in Palestine.

Stellar Clocks

We have seen that the Egyptians began their year by stellar observation. They must have begun very early the determination of the hour also by observation of the stars. The word "hour" was written in hieroglyphic in the earlier period of Egyptian writing, with a *star* after it as the so-called "determinative." In order to use the night-sky as a stellar clock it was necessary that the observer should build up a list of important stars together with the times at which they crossed his meridian at different seasons of the year. If complete for all the seasons such a list would enable the Egyptian at any time of year to observe the night-sky and determine the hour. He seems to have devised a primitive type of "transit instrument" intended to enable an observer to determine the instant when a given star crossed his meridian. Naively simple and undeveloped, this instrument was employed as the observer sat cross-legged on the flat roof of a building, supposably often a temple. Opposite him at the other end of the building squatted his assistant facing him, and both of them exactly on the same meridian which was probably marked on the roof. We know that the Egyptian engineers and surveyors of five thousand years ago could lay down a meridian with a good deal of accuracy. The oldest pyramid, that of King Snefru at Medum, was oriented in the thirtieth century B.C. with surprising accuracy. Our astronomical observer, seated on a meridian line which we may regard as fairly accurate, peeped through the forked top of a palm branch which he held in his hand as a kind of sighting staff, and sighted through the slot in the top of the palm branch at the stars in the opposite northern sky over the head of the squatting assistant. A star rising to culmination

over the assistant's "crown," that is, the exact center of his head, might be over his "left eye," over his "left ear" or over his "left shoulder." These positions were determined with some precision by the use of a plummet. As the observer looked through the slot in his sighting staff, he held his plummet well out in front of the staff, so that the plumb-line at a point near its top cut through the star he was observing, and at a lower point just above the weight the plumb-line also cut through some part of the head or figure of the observer's assistant squatting at the other end of the building. The plumb-line then cut through one shoulder, one eye or one ear of the assistant. Thereupon the observer could wait until, as he followed the star with his plumb-line past the ear and the eye, the plumb-line finally cut through the top or crown of the head. The star was then in culmination and was crossing the observer's meridian. This was the most important function of the device. It was chiefly a transit instrument and as such is the oldest known astronomical instrument. It was called in Egyptian a *mrḫ · t* or *merkhet*, meaning "instrument for knowing," to which we should add the word "hour." As an "instrument for knowing the hour" is of course a timepiece, we may regard *merkhet* as the earliest known word for "clock."

It is obvious, as Borchardt has observed, that these meridian observations themselves would necessarily have had to be accompanied by some kind of time record such as is furnished to-day by the astronomer's clock. He has supposed that the Egyptian observer originally compiled a time-table of hours when important stars crossed his meridian or occupied definable positions near it, which could be stated in terms of the head and shoulders of the observer's squatting vis-à-vis. Two such star-tables have been preserved, pictured in the tombs of Ramses VI and Ramses IX at Luxor, that is, about 1150 and 1120 B.C. The positions of the stars are given at twenty-four different times of the year, that is, twice a month, on the first and the fifteenth. These tables very much need detailed study by an experienced astronomer. Thus far the only star identifiable is Sirius, and his only determinable position is his culmination. These position-tables must have been accompanied by time-tables, probably on papyrus, which now seem to have perished.

Water-Clocks

Evidently some kind of timepiece was employed in the compilation of these time-tables, otherwise the culminations observed would not have furnished any indications of time. Borchardt has demonstrated that the Egyptian water-clock, the famous clepsydra, or "water-stealer," as the Greeks called it, was used for measurement of the hours of the *night* and has therefore concluded, with much probability, that it was a clepsydra which was used to furnish the time data which transformed the night-sky for the Egyptian into a vast stellar clock.

There were two types of the clepsydra, one which we may call an *outflow* clock, and the other an *inflow* clock, according as the water flowed out of, or into the graduated vessel serving as the clock. In both these forms of clock the principle was essentially the same. Of the inflow type, which seems to have been the more accurate system only two specimens are known to me. Thirteen examples of the outflow type have been preserved in whole or in part. The oldest of them bears the name of Amenhotep III, and therefore dates from around 1400 B.C. We know, however, of a maker of such clocks, who lived 150 years earlier, about 1550 B.C. This man, whose name was Amenemhet, is the earliest known astronomer, physicist and clock-maker in the history of science. He left a brief

autobiography engraved on the wall of his tomb-chapel in the great cemetery of Egyptian Thebes, which lies opposite modern Luxor. Amenemhet proudly tells us that he lived and served at the court of the first three pharaohs of the eighteenth dynasty. He takes evident satisfaction in relating that he made a clock for Amenhotep I, that is, some time in the middle of the sixteenth century B.C. He avers that he had read all the existent literature on the subject, as a modern scientist might do. Whether in the course of this reading, or as a result of his own researches, does not appear, but our clock-maker tells us of his observation that the winter night was fourteen hours long, while the night of the harvest season (summer) was twelve hours long. He mentions that he constructed his clock in accordance with the fact that he had noted an increase in the length of the nights from month to month and also a decrease from month to month. He then goes on to say: "I made a clock (*mrḫy·t*) computed for the year . . . [it was correct (?)] at the going in of the harvest season (summer) in the cultivation season (winter), at the union (?) of the moon with its seasons. Every hour was at its time."

Externally this clock, built by Amenemhet for the king of Egypt, was of unique interest, for it was the earliest timepiece of which we have any record, fitted with tiny statuette figures so devised that they appeared at the proper intervals and indicated the hours. Unfortunately, the text of Amenemhet's autobiography is much damaged and very fragmentary. His description of these mechanical arrangements informs us that "Nekhbet (the Moon-goddess) walked at the same time with Re (the Sun-god) [while she extended the symbols of life and prosperity] which were in her hand, to the nostrils of his majesty. Then she went down (meaning she dropped out of sight) . . . ," and unfortunately at this point there is a bad gap in the text, after which we find the words: "[and Re] rejoiced when he saw these goddesses ascending and descending before him." As Sethe has noticed, "these goddesses" are obviously the well-known hour-goddesses, each personifying an hour. Amenemhet had evidently arranged small figures of these goddesses, each of whom came into view at the proper point of time, thus by her appearance announcing the hour. It must be borne in mind that these figures belonged to a water-clock and not to a mechanical clock of cog-wheels and gears, for such mechanical developments were devices entirely unknown in the sixteenth century B.C. They did not come in until the Hellenistic Age, after Alexander the Great. We may suppose, with some probability, judging from the verbs of motion employed in the description, that the moving figures were attached to floats on the surface of the water in the clock, and that they therefore moved up and down with the changing level of the water. It must have been a pleasing and picturesque timepiece which Amenemhet devised, and he tells us with evident satisfaction that it pleased the king. It was the earliest of these ingenious artistic mechanical clocks of which we see the first reaching Europe when Saladin sent such an elaborate timepiece to the Emperor Frederick II in A.D. 1232.

Amenemhet's fragmentary description of his elaborate clock, combined with all the data now observable from an examination of the surviving Egyptian water-clocks, especially the oldest of the outflow clocks, does not reassure us regarding our ancient astronomer's ability to construct an accurate timepiece. In the simplest terms this device consisted of a water vessel, with a hole in or near the bottom for the escape of the water and a graduated scale of hours engraved on the inside from the top to a point near the bottom. To a modern scientist it

would be axiomatic that the sides of the water vessel should be vertical and parallel; or, stated more simply, the vessel should be a cylinder. To our surprise, however, we find that all the Egyptian water-clocks are inverted truncated cones. The only reason I can suggest for this unsuitable form is that its flare made the scale of hours on the sloping inside walls of the vessel more accessible and more legible. Of the complications which this form added, the Egyptian's limited knowledge of hydraulics left him wholly unaware. If the column of water had been cylindrical, its rate of escape would have been greatest when the column was highest, that is, when the greatest pressure was being exerted on the water escaping at the vent. This variation in the rate was obviously increased by giving the vessel a flare, so that the upper half contained a much greater volume of water than the lower half.

The Hour

Now the function of such a clock was to divide the night into twelve equal parts. There was, however, no sufficient method for securing a uniform flow of water during each one of these twelve parts. The hours decrease too rapidly in length from the beginning to the end of the scale of hour marks on the inside of the vessel. Only in the middle is one hour that is approximately correct. Amenemhet indicates that his clock was adjusted to show the hours for all seasons of the year. His narrative, as well as the surviving water-clocks, show that whether the night was short or long, it continued to be divided into twelve periods, that is to say, in winter each of the twelve periods of the night was longer, and during the nights of summer each of the twelve periods was shorter. In other words, the hours were not of constant length. We are accustomed to a flexible *day* of varying length, but an *hour* of elastic length is surprising to us. The scheme of marks was intended to indicate the lengths of the nights in all the different seasons. Indeed the later water-clocks provide for indicating a change in the length of every night, from night to night, and in the period around 300 B.C. these indications were essentially correct.

The Hour and the Twenty-four-Hour Day

The twenty-four-hour day, with hours of variable length, longer in the winter nights and shorter in the summer nights, or longer in the summer days, and shorter in the winter days, reached Greece with the Egyptian clocks in the time of Alexander the Great. We know that an Egyptian clock was shown to the cynic Diogenes as something unusual and curious. It passed thence to Rome, where the first sun-clock appeared in 293 B.C., having come into Italy by way of the Greek cities of Sicily. The first water-clock did not arrive in Rome until 159 B.C. It is important to notice that the Greeks and Romans both had small divisions of the day long before this. Homer knew of divisions of the night determined by observation of the constellations, and Herodotus tells of Babylonian devices for determining divisions of the day. The oldest evidence of the twelve-hour day in Greece is in the Homeric studies of Aristotle, where he refers to "the twelve parts of the night" (*τῆς νυκτὸς αἱ δώδεκα μοῖραι*).

The Egyptian hour of varying length, which thus came into Europe with the twenty-four-hour day, remained in use nearly down to the end of the Middle Ages. The Babylonian *bêru* (formerly *kasbu*), a period of one sixth of day or night, was of fixed length, and may eventually have had some influence on the European hour; but the hour of fixed length did not come into general use in Europe until the fourteenth century of our era, when it was introduced by the striking clock, which inevitably gave it wide currency.

Subdivision of the Hour

We have already seen that primitive life did not possess the subdivision of the day into hours. Much less did it have any shorter divisions of time. There are of course inexact terms of no fixed significance, as we say, "the twinkling of an eye" or the German "*Augenblick.*" For a vague period of about half an hour, the natives of Madagascar say, "a rice-cooking," while for a moment they say, "the frying of a locust." The Cross River natives say, "a complete maize-roasting," for something less than a quarter of an hour. In Illinois when I was a lad, a farm-hand would facetiously indicate a moment by the phrase, "two jerks of a lamb's tail." The shortest interval of time indicated by the Egyptian was written in hieroglyphic simply by the upraised head of a hippopotamus, with a horizontal line cutting it off. This line was intended to represent the surface of the water, and the idea suggested was that of the instant of time during which the hippo cautiously thrust his head out of the water for a quick glance around and its almost instantaneous disappearance. That was the Egyptian scribe's ingenious writing of the word "instant"; but this word did not indicate a subdivision of the hour. In so far as we can discern, the hour was divided in early Christian times in Egypt, into the half, the quarter, the eighth, etc. The sexagesimal subdivisions of the hour into minutes and seconds, now customary with us, are not earlier in the Orient than about A.D. 1000, and they did not appear in the western world until the end of the Middle Ages. The source of these divisions is unknown, but it has been suspected with some probability that the Arabic astronomers applied them to the hour from the use of them in dividing the circle, in which connection they are likewise not of early oriental origin. Even Ptolemy did not divide the circle into sexagesimal degrees, although he did apply the sexigesimal divisions to the radius of his circle.

There are indications of a small division of time employed by the Egyptian surgeons at an early date (nearly five thousand years ago) for the counting of the human pulse, and it is known that Hippocrates some twenty-five centuries later was already counting the pulse. Obviously some subdivision of the hour, and some timepiece for measuring it, must have been used for this purpose. The surprisingly accurate determinations of the length of the planetary revolutions by the Chaldean astronomers must have required timepieces adapted for use in measuring fractions of time smaller than the hour. No examples of Babylonian timepieces have survived, however, and the whole matter awaits further investigation.

Eras and Periods Longer than a Year

Of periods longer than a year the primitive mind had but the vaguest conceptions. Indeed primitive men may entirely lack the *conception* of even a year. In the Philippines the Bontoc Igorots have no notion of a year. It is of course possible to count a series of years without any notion of the year itself. The Bataks of Sumatra use smallpox epidemics as marking-off periods, usually nine to twelve years in length, and a native will say that his house is "two smallpox epidemics old." The Hottentots keep records of the ages of their live stock by the number of calvings or lambings. But among people of lower intelligence there is no conception of a long period of time. A Dahomey Negro rarely knows how old he is, and we are all familiar with the old darky who has no idea of his age.

With the advance of civilization man's increasing knowledge has had a profound influence upon his conceptions of time,

and especially his discernment of ever-lengthening periods of time. The astonishingly long reigns claimed for their early rulers by the scribes of Egypt and Babylonia must have been compiled in a primitive age of naive and childish fancies, whose fantastically impossible periods could not have grown out of any just impressions of time as measured by human history. The flow of time was not at first revealed to man by the processes of nature. The erosion of a river valley and its changing contours would not be discernible, because the early observer had no knowledge of how those contours looked one thousand years earlier. But when he saw a huge pyramid with gaping holes gnawed into its flanks by the biting sand-blast which the powerful Egyptian north wind drove against it, he knew just how that pyramid slope had looked when it left the hands of the architect a thousand years earlier. Thus the slow decay of the works of man taught him what the processes of nature could not at first have revealed. Such unwritten human records in Babylonia and Egypt began to reveal to men after 3000 B.C. the slow march of time, which became more and more evident as those records gradually took written form. The earliest known annals of a nation compiled in the twenty-eighth century B.C. covered some fifteen hundred years of human history, that is, they extended from the forty-third to the twenty-eighth century B.C. The men of the Pharaoh's court, therefore, in the twenty-eighth century B.C., that is, some 4,700 years ago, could look back upon a lapse of time a little longer than that which we survey as we contemplate the period that lies between us and the so-called fall of Rome in A.D. 476. For those men time had long since ceased to be a discontinuous duration. The earliest mention of an era appears on a monument of Ramses II in the thirteenth century B.C., a monument which is dated in the year 400 of an era which had begun about 1720 B.C.

In Babylonia the cycle of nineteen years for the intercalation of the lunar months evidently discloses a conception of time as a continuous flow of duration. It was introduced in 528 B.C.

Science and the Continuous Flow of Time

It is evident that historical impressions of the long and continuous flow of time, especially for some centuries before the beginning of the Christian era, had led the men of the Hellenistic Age and the early Roman Empire to their dreams of a thousand years, which have left us the rather misleading significance of the word "millennium" as a Golden Age.

It is rather natural science than human history which has so enormously expanded our modern conception of the flow of time. About 400 B.C. the Chaldean astronomer Kidinnu, whom the Greeks called Kidenas, discovered the precession of the equinoxes, involving a cycle of twenty-six thousand years. That was the longest period revealed by the vast celestial clock for many centuries, indeed, perhaps even into modern times. It was followed by the geologists' estimates of the length of the periods required for the formation of the earth. Much more precise are their computations of the length of the much later process which has produced the present surface of the globe. In our prehistoric survey of Northeastern Africa, it has been possible to date the desiccation of North Africa in the middle of the Old Stone Age and to show that the sand dunes of Nubia, as they marched southward, left the North African coast of the Mediterranean about thirty-five thousand years ago. The computations of De Geers have shown that it is about nine thousand years since the retreating ice of the Glacial Age reached its present latitude, while the investigations of the American geologists would indicate that

the Ice Age began probably a million years ago. Such researches, especially the field investigations of our own Prehistoric Survey in Northeastern Africa, have revealed to us this imposing panorama of terrestrial processes as the vast stage where we discern earliest man emerging as the only implement-making creature, whose prehistoric life is thus disclosed interlocking with the processes of nature, which formed our globe. It is a tremendous spectacle: the geological process, marching hand in hand with the cultural advance of man.

Such disclosures of the position of man in the universe form for us the culmination of man's sense of time as an historical process no longer discontinuous. We begin to feel a range of time measured by the emergence of the life of man in the universe, until we are aware that there is no time apart from man. Those celestial processes with which our knowledge of duration now begins, as they are disclosed to us in incomprehensible gulfs of millions of light years, are for us essentially timeless. We now recognize that modern investigation of early man has revealed him to us filling the gap between the incalculable duration of the celestial processes on the one hand and on the other the more comprehensible periods of the terrestrial processes that formed our globe as the home of man and led over to the historic age. Thus in vastly remote prehistoric ages, when the present surface of our globe was being fashioned by geological forces, we begin to see man, all unconscious of those forces about him, but suddenly revealed to us rising out of them and entering a realm of time, because he was, and still is, the first and only creature to be aware of time. He was its creator, the first being possessed of the ability to look back along his own trail and to recognize the point in the timeless process of the universe where the creature man entered a new and mysterious realm, which by that very fact made him the creator of a domain of time.

ARCHEOLOGICAL PERU

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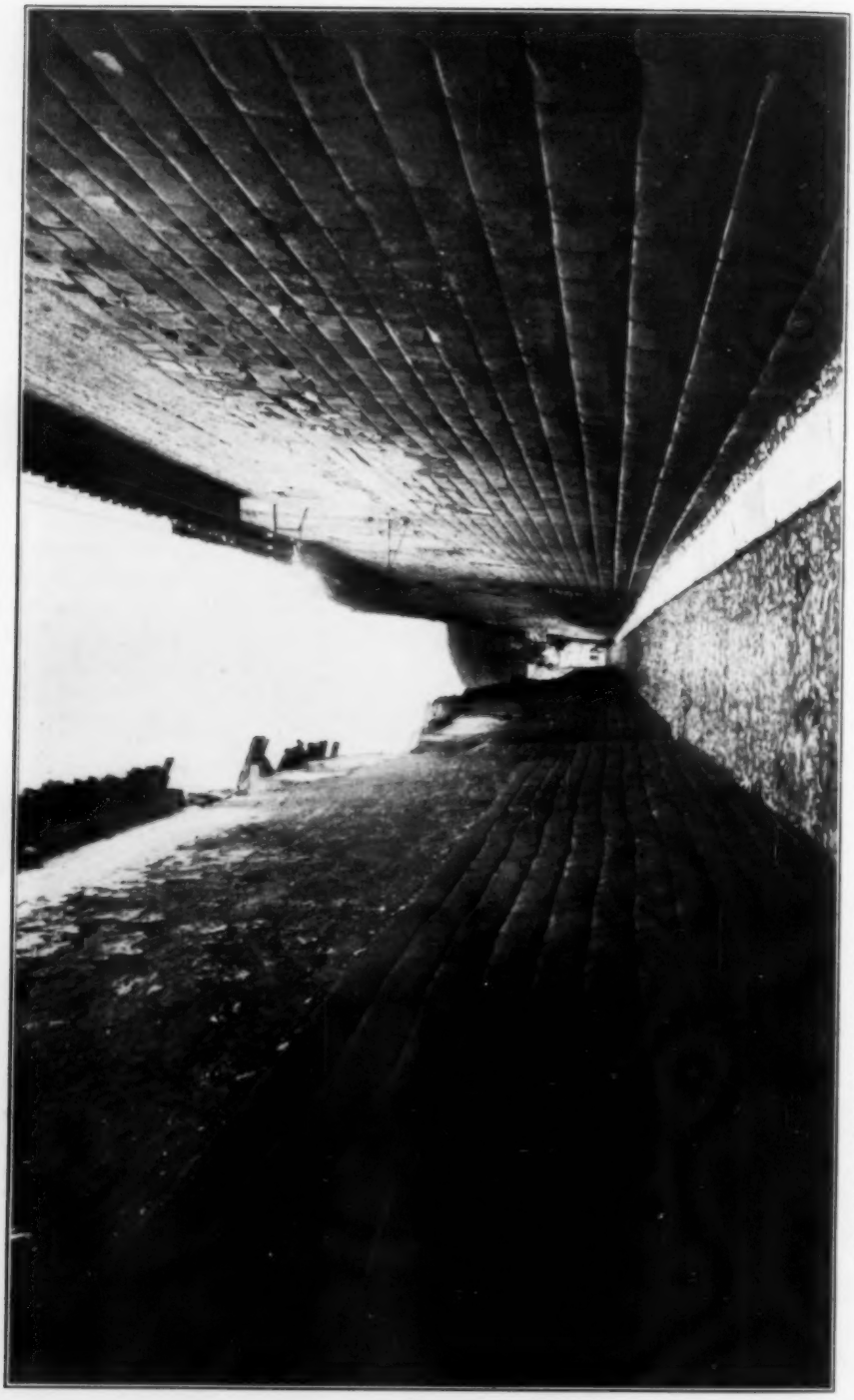
In pre-European times the western slope of the Andes was the high civilization center of South America. At the coming of the Spaniards, in 1532, the Inca empire dominated this Andean region. Their domain stretched from central Colombia through Ecuador, Peru, Bolivia and northwest Argentine to the Rio Maule in southern Chile; from the long Pacific coast line on the west across the high Andes to disappear in the Amazon jungles to the east. Just how far the Inca influence penetrated the jungles is not known, for the heavy undergrowth makes archeological investigation almost impossible, but there are suggestions that the extension may have been much greater than modern evidence has thus far revealed.

The Spaniards sought the Inca empire because of the tales of unlimited gold. The history of their conquest is well known, as well as the accounts of the quantities of gold objects found. The stories of the early historians are hard to believe, since vessels of all descriptions, ornaments, costumes, crowns, benches, even imitation flowers and stalks of corn were said to have been made of pure gold. Still, recent archeological finds show a skill and variety in the fabrication of gold which makes even the wilder tales seem reasonable. For example, one might describe a pair of gold earplugs, made of delicately incised cylinders ending in four-inch disks, with embossed figures, each holding a goblet in one hand and a flute in the other and covered with attached projecting roofs from which dangle gold hammered birds.

PUMA PUNCU, PART OF THE RUINS OF TIAHUANACO, BOLIVIA

THE STONES ONCE FORMED A FLAT PLATFORM, WITH THE ROW OF CUT STONE SEATS ALONG THE EASTERN SIDE. THE STONES WERE HELD IN POSITION WITH COPPER CRAMPS. THE FLAT STONE IN THE CENTER IS CALCULATED TO WEIGH OVER 100 TONS.



LORETO STREET IN CUZCO, PERU; A STREET IN THE ANCIENT CAPITAL OF THE INCA EMPIRE

THE STONE WALLS ON BOTH SIDES THE STREET ARE PART OF THE OLD INCA CONSTRUCTION OF SMALL BLOCKS IN QUESED MASONRY. ON THE OLD STONE WALLS THE MODERN ADOBE WALLS OF THE PRESENT INHABITANTS OF CUZCO ARE PLACED.

However, in addition to gold the Spaniards found many more things, some of economic importance and some of interest to the curious, but all amazing enough to the observers to be faithfully recorded in the accounts of this new land. They found an extensive empire with a large, well-disciplined population. Some were trained as miners; some as metallurgists; some were special weavers; and some expert in the carving of stone. Many were laborers on farm or in town. Selected individuals were special officials. In fact, the social organization of the Incas was developed to an amazing completeness in respect to the regimentation of labor and social security to the individual. Families were organized in units of ten, each supervisor of a ten-unit was again part of a unit of ten supervisors, and so on up the great pyramidal structure to the ruling Inca whose word was authority for the whole kingdom. The system was both the strength and the weakness of this civilization: its strength, because it organized a vast empire with the maximum efficiency of the materials and the mechanisms available, for the benefit of the greatest number; its weakness, because the officials, accustomed always to receive orders, lacked experience in giving them. That this was vital in times of stress is shown by the relative ease of the Spanish conquest. With the chief gone, the system disintegrated.

Communication between various parts of the extensive region was well developed. Stone-paved roads stretched for miles between important points. Suspension bridges swung across gorges and rivers. With a relay system of trained runners a message or a small article could be delivered in remarkably short time. Sections of the paved roads still exist, passing through territories which are laboriously traveled to-day. The stone piles of the suspension bridges still mark the trails of the Incas.

The architects planned and executed complex temples, houses and forts of adobe brick, stone or combinations of the two. Ordinarily only adobe brick was used along the desert coast of Peru, where rain is not a factor of destruction, while all stone buildings were common in the rainy highlands, where stone is not only advantageous but available. Many of the Inca buildings were of rough split

A STREET IN PACHACAMAC

stone, selected and piled, and sometimes calked with clay. The true arch was not known, but a corbeled dome of projecting stones weighted down from behind was erected and covered with clay for a rainproof roof. Many of these rough-stone (*pirca*) walled ruins of forts and villages are found throughout the high-

POTTERY OF THE MIDDLE AND LATE CHIMÚ PERIOD

LEFT, TWO BOWLS ILLUSTRATING INDIANS CARRYING MUMMY-BUNDLE LITTERS; CENTER, BLACK WARE PORTRAIT JAR; A BLACK WARE, DOUBLE-WHISTLING JAR, WITH MODELED ANIMAL WHISTLE;[1] EXTREME RIGHT, A JAR REPRESENTING AN INDIAN SITTING UNDER A SHELTER.

lands and mark the advance of the Incas. However, more important buildings were made of cut and fitted stone. At first stones of different sizes were carefully hewn and planlessly fitted into a wall. Later, the stones were cut into more or less unit-sized blocks and fitted into a coursed wall. Niches were left in walls for decoration, and wedge-shaped doorways were typical. Perhaps the supreme effort of Inca construction, notable both for complexity and for fineness of workmanship, is the famous ruin of Machu Picchu, near the ancient capital, Cuzco.

Minor arts were also emphasized in this civilization. Weaving was one of its great technical and artistic achievements. In Inca times the weaving was reduced to quantity production, the designs were geometrical and the elaborate pieces less frequent than in the pre-Inca periods to be described later. In pottery making the same tendency toward geometrical design is seen. However, the shapes of the Inca vessels are characteristic of that phase of Andean civilization and mark the presence of Inca influence wherever they are found. Typical are a pointed base, high-collared jar or aryballus, a shallow bird-handle dish, and a loop-handled bowl on a pedestal base. Besides gold, silver and copper were fabricated, and copper was alloyed with tin for tools. Bronze axes, chisels, knives and club-heads were made, as well as many copper and bronze ornaments. Stone and bone were also carved into ornaments and tools.

The accounts of the Incas are largely a matter of written history, recorded at the time and in the years that followed the conquest. Many of the recorded facts have been checked by archeologists, and numerous details have been supplied by excavators. Before the Incas, the history of Peru is largely based on archeo-

[1] Water when poured from one section to the other (accomplished by tipping the jar) forces air out through the whistle at the top and emits a mournful note.

logical reconstructions. The Incas in the eleventh century were a small tribe living in the valleys around Cuzco, Peru. Their expansion from the Cuzco area, north and south in the highlands, down to the coast of Peru, and eventually to the maximum extent of their empire, took almost four hundred years. Part of the time was consumed in building up a military and social organization that could conquer and assimilate neighboring tribes. But there were other difficulties as well. One of the major obstacles of this expansion was the varied topography of the Andean region.

The contrasting environment of coast and mountain has always been an important factor in Peruvian history. The coast of Peru is virtually a desert through which the rivers, which originate in the mountains, cut their way to the ocean and provide fertile valleys and water to an otherwise uninhabitable area. Between the river valleys are desert stretches, which, though not impassable, discourage frequent travel and are a sufficiently isolating factor to cause the development of local industries and styles in the various valleys. The mountains present a complete contrast, with high altitudes, an abundance of rainfall and deep gorges. Stretching from Bolivia to central Peru is the high plateau, or altiplano, on which lies Lake Titicaca at 12,000 feet above sea level. The plateau is cultivable, in spite of the cold nights and the absence of trees or shrubs. Isolation is largely due to distances rather than to natural obstacles. As a corollary to the contrasting coast and highland environment is a difference in materials and products. Stone is abundant and desirable for building material in the highlands, while adobe is more practical on the coast. Potatoes are the basic product of the plateau, corn of the coast. Cotton is the lowland fiber; wool the highland fiber, since it comes from the mountain llamas and vicuñas. The net result of all these environmental differences was a series of obstacles to the expanding Incas, who had to build roads where none had been before and who were forced to meet conditions to which they were not accustomed.

STEPS OF STONE

LEADING FROM ONE TERRACE TO ANOTHER IN THE ADOBE BRICK PYRAMID, OR FORTRESS, OF THE RUINS OF PACHACAMAC, NEAR LIMA, PERU. A PAINTED CLAY PLASTER IS SEEN COVERING THE BRICKS IN THE WALL ON THE RIGHT OF THE STEPS.

Another difficulty which the Incas faced in their expansion program was the people who already lived in these

TYPICAL INCA POTTERY

ON THE LEFT IS A SHALLOW DISH WITH BIRD HANDLE. NEXT IS THE TYPICAL POINTED BASE, ARYBALLOID JAR, PAINTED WITH GEOMETRIC DESIGN. THE WOODEN GOBLET, WITH LACQUER DESIGN, IS AN INCA ARTIFACT WHICH CONTINUED WELL INTO SPANISH TIMES. FINALLY, ON THE RIGHT, IS A LOOP-HANDLED BOWL.

A GENERAL VIEW OF THE CITY OF CHAN-CHAN

NEAR TRUJILLO, PERU. THE SURF OF THE PACIFIC IS SEEN IN THE BACKGROUND.

various regions. In Bolivia were the Aymaras or Collas, whose ancestors had developed Tiahuanaco civilization which at one time encompassed in its influence all Peru, Bolivia and parts of Chile and even Ecuador. On the northern coast of Peru were the Chancas, who constituted an additional formidable resistance to the invasion. Similar resistance was met in every region, because the Andean area was well peopled. Many of the regions which the Incas conquered had a heritage of civilization which antedated the Inca tribes by centuries. These pre-Inca civilizations have been the most fruitful fields for research of the archeologists.

AN INCA BRIDGE

PART OF A PRE-SPANISH HIGHWAY WHICH STILL SERVES THE MODERN INDIANS.

In the pre-Inca periods there is no background of traditional records; at best, the myths are sketchy and not very reliable. The archeologist must make his chronological divisions on the basis of typological differences in materials found and in the stratigraphic relation of one style to another. The basic divisions refer to the geographic environments mentioned before. On the north coast of Peru a series of adjacent valleys formed a unit with certain outstanding characteristics which could be contrasted with other regions, such as a group of valleys on the central coast or the southern coast or with various areas of the highlands. These regions were named with reference to the valleys in which the most typical material was found. Thus the northern coast forms the Chimú region; the central coast, the Rimac region, the southern coast, the Nazca region; the southern highlands (Bolivia) the Tiahuanaco region; and the central highlands, the Chavín region. Within each region, periods were distinguished chronologically into three rough categories, Early periods, Middle periods and Late periods, all preceding the final domination of the Incas.

Part of the chronological division into periods has been based on direct stratigraphy, that is, the superimposed position of one style over another. Pottery gives the clearest identification of style, although textiles, small artifacts and even buildings may serve. At Tiahuanaco, for example, one pit excavated by the author revealed a layer of Early Tiahuanaco material at a depth from about 8 to 15 feet below the surface. Above this was a layer of Classic Tiahuanaco material at from 3 to 8 feet. From the

surface to 3 feet were Decadent Tiahuanaco objects, and on the surface itself was Inca material. This type of direct stratigraphy is rare, however, and almost non-existent on the coast. Dr. Uhle found another type of direct stratigraphy on the coast at Pachacamac, where one temple had been built over an older one which had fallen into disuse. He associated graves, and the accompanying burial material, with the old temple ground surface, the old temple débris and the new temple ground surface.

Still another method of distinguishing periods and phases is that of grave association and isolation. On the premise that objects found in the same grave are contemporaneous, a group of graves can be associated by the presence of the same type of objects, as, for instance, typical Inca pottery. At the same time non-typical objects may be found in the graves which form a group, contemporaneous with but not related to Inca. In another group of graves this second class of objects may be found without the Inca associations, that is, isolated from Inca. One may deduce from this that the second class of objects existed previously and persisted into Inca times. By continuing this type of association with the second class, a third class of objects may be associated and then isolated, so that a chronology of types is set up, step by step. Obviously this method has its limitations, but in a large series of graves it has proven its merit.

Further identification is based on association of pottery style with textile design style, and even with the painted and the arabesque reliefs on adobe walls. Certain chronological implications can be gathered from the shift in a design style, from a realistic to a stylistic, for example. In fact, there are many details in the techniques used to determine chronology. However, assuming the labor completed, for the moment, a picture of the present status of archeological history in pre-Inca times can be given.

The Early periods in the Andean region are the oldest now known, but they are not primitive in the quality of the work done. Indeed, nothing which can be identified positively with a primitive or archaic phase has been uncovered so far. The Early periods, on the whole, represent the acme of artistic and technical achievement in pottery, weaving and perhaps architecture. All Early periods, although differing in detail in the various geographical regions, tend towards realism in design style.

Early Chimú, on the north Peruvian coast, and Early Nazca on the southern Peruvian coast are both claimed, by various authors, to be the oldest known Peruvian period. Without entering this argument one may say that both are contemporaneous throughout most of their duration, which, according to Philip Ainsworth Means's chronology, is from something B.C. to about 500 A.D. Recent investigation suggests that Tiahuanaco and Chavín phases might also be contemporaneous with these coast periods.

The style of the Early Chimú period is notably one of realistic representation of contemporary life. Most of this was represented in pottery. Houses, plants, animals and scenes were modeled out of clay, as well as most remarkable and realistic portrait jars. Painted on the vessels, in reddish-brown on buff, were scenes of hunting, weaving, fishing, dancing and many other daily events. Pottery was shaped into large flaring mouth bowls or jars with double tubular spouts which curved up to meet in a single spout, known as "stirrup" spout jars. Cloth is scarcely known from this Early period, probably due to poor excavating, but skilfully fabricated gold and silver objects have been found. Large cities were built of adobe brick. Chan-Chan, the capital of the kingdom, still remains as the largest single town in the Andean archeological region.

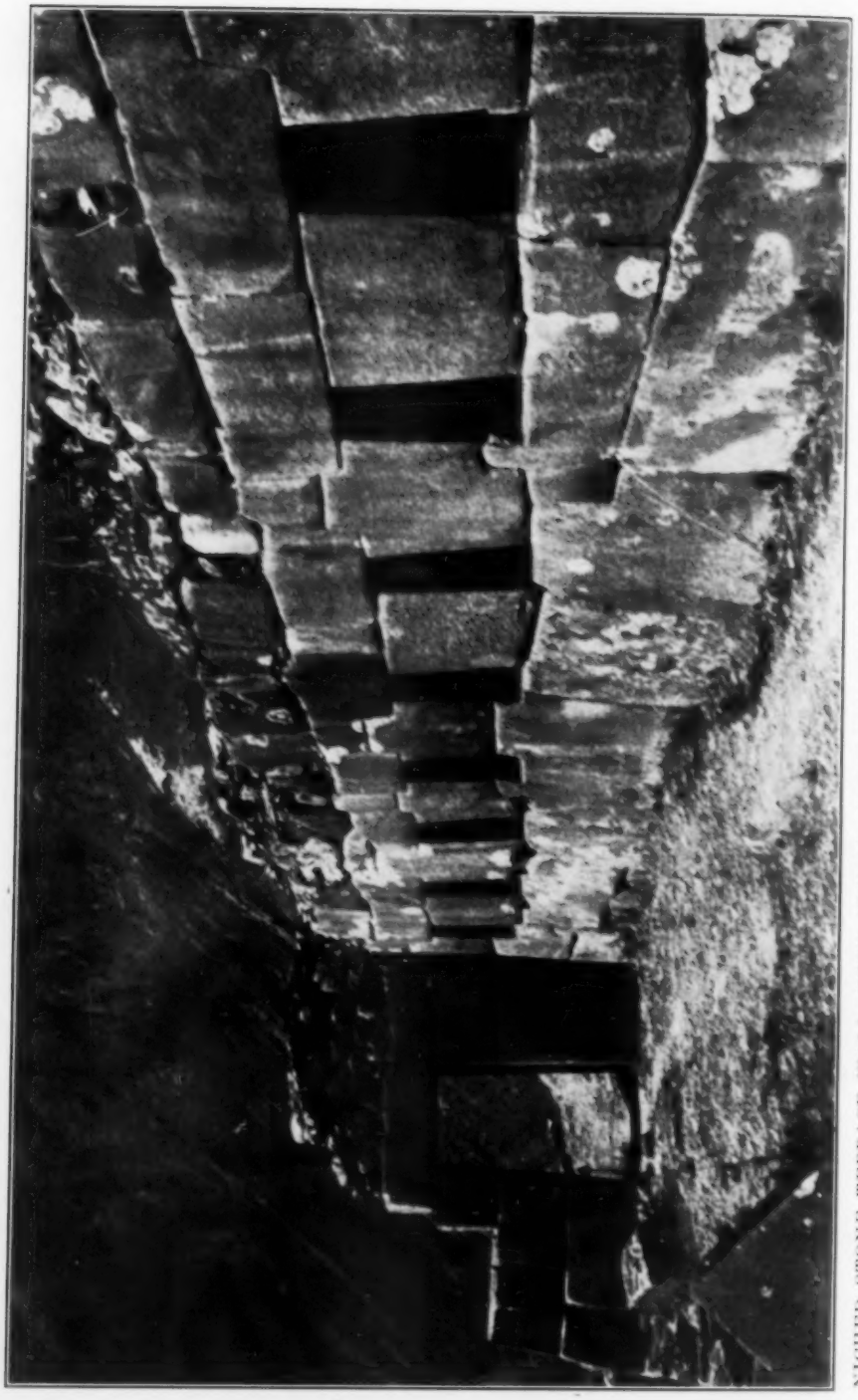
The Early Nazca style presents ceramic paintings of mythical figures in polychrome. The realism is not as pronounced in this style, particularly as representing scenes of daily life is not a part of the art. The figures of elaborate cat demons, warriors and multiple-headed gods are stylized, but still

CEREMONIAL URN OF TIAHUANACO–EPIGONAL TYPE

PAINTED WITH A WARRIOR FIGURE SIMILAR TO ONE CARVED IN STONE AT TIAHUANACO ITSELF. THIS URN WAS FOUND AT NAZCA, PERU; ILLUSTRATES THE SPREAD OF HIGHLAND TIAHUANACO STYLE TO THE COAST.

painted with an admirable freshness and variety of color. Pottery shapes are characterized by a globular bowl with a double spout connected by an arching bridge, and also a cup and tall vase with double curved sides and round bottoms. The Early Nazca period is noted for the excellent weaving, and particularly for elaborate polychrome embroideries which incorporate the same mythical god figures seen on the pottery. In many respects the variety of weaving achievements of the Early Nazca artists was not surpassed in any later period. Buildings in this period were made of adobe brick and are not particularly characteristic.

The Classic Tiahuanaco in the highlands of Bolivia, around the southern end of Lake Titicaca, was probably roughly contemporaneous with the two Early periods just described. Little in-



NICHED STONE TERRACE WALL, WITH WEDGE-SHAPE INCA DOORWAY, AT THE RUINS OF OLLANTAITAMBO, NEAR CUZCO, PERU

fluence of coast style can be found in this period. In spite of that fact, trade must have been common, because Early Nazca textiles are made from both wool and cotton, the former being the hair of the llama and vicuña, both highland animals. Tiahuanaco design style depicts pumas, condors and warriors as typical motives, outlined in black and filled with white, yellow, brown and gray, all on a red slip background. The typical shapes are a flaring-sided goblet, a flaring-sided flat-bottom cup, a vase and an open wide-rim bowl. No cloth has been found in the wet highlands, but incised designs on stone statues probably were copied from contemporaneous existing textile garments. Monolithic statues are characteristic of the Tiahuanaco period. Stone, moreover, is the typical building material. Huge blocks, pillars and slabs were cut, dressed and jointed into position. Copper cramps were used to hold massive blocks in position. The achievements of the Classic Tiahuanaco period in stone cutting amazed the Incas when they discovered these ruins during their conquest of Bolivia.

The Middle periods in general mark the influence or actual domination of the highland Tiahuanaco over the coast and highlands of Peru. Almost pure Classic Tiahuanaco has been found on the coast, although in small quantities, but the applied designs, on pottery shapes already existent in the coast periods, are common. This active influence is followed by various sub-periods with local variations on the Tiahuanaco-influenced or "Epigonal" types and style. There is again regional variation, but the whole area is closely knit together by this common influence. The general tendency of design is towards stylization, away from the realism which had existed previously.

The Late periods on the coast of Peru are secondary developments in the local geographic areas. Thus, on the southern coast, the Late Nazca (or Ica) is a local development of geometric, "textile" pattern designs on new shapes, not related to their Early Nazca predecessors. On the northern coast the Late Chimú is characterized by black modeled pottery. In general, the Late periods stress geometric design. This is particularly noteworthy in textiles, where single motives are repeated again and again. Gauze, tapestries and painted cloth are common in the Late periods, while the elaborate embroideries are missing.

In this brief sketch an outline of the Inca and pre-Inca periods of Peru is presented. The beginning is not known, although an elaborate textile, ceramic and architectural art such as that found in the Early periods implies considerable time for development. Likewise, the other end of the history was cut short by the arrival of the Spaniards. What solutions the Incas might have found for their problems will never be known. The past, however, will be more clearly revealed as the quantity and quality of the archeological work increases, and then another chapter will be written on what preceded the pre-Inca periods of Peru.

THE RISE OF PHARMACOLOGY

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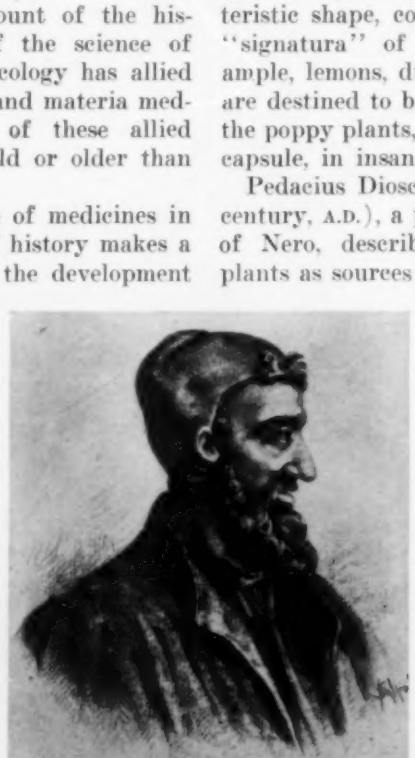
IT is a remarkable fact that while the history of medicine as a whole and its preclinical and clinical branches has been adequately portrayed by many authors, the history of pharmacology proper has been entirely neglected. It has been said with some justice that the study of the historical development of a subject very often reveals its true nature. The history of pharmacology, then, will acquaint us with the task and problems of this science. It is the purpose of this review to present for the first time a brief account of the historical development of the science of drug actions. Pharmacology has allied sciences—therapeutics and materia medica—and the history of these allied sciences is indeed as old or older than civilized man.

The story of the use of medicines in the different periods of history makes a fascinating chapter in the development of knowledge. The concepts and practices of this art are deeply colored by the superstition, religion, philosophy and science of the ages. History does not record a time when man did not employ herbs and other medicinal agents for the relief of suffering. Primitive man was attracted to animate and inanimate objects of nature with characteristic shape, color, taste or odor, and attributed mysterious virtues to them and tried their efficacy in the hour of distress. His continued use of them, however, was rarely founded on any more rational basis than his use of charms, amulets, magic and sorcery for the same purpose. A superstition originating perhaps in prehistoric times but systematized and exploited in the Middle Ages was the unfortunate belief in *signaturas*. According to this creed nature pointed out the therapeutic usefulness of every substance, especially plants, by a characteristic shape, color, odor or taste (the "signatura" of the plant). For example, lemons, due to their heart-shape, are destined to be used in heart disease, the poppy plants, with their head-shaped capsule, in insanity.

Pedacius Dioscurides (middle of first century, A.D.), a physician in the service of Nero, described over six hundred plants as sources of medicines and dealt with their aromatic, oily, gummy and resinous products. He is honored as the "father of materia medica."



CLAUDIUS GALEN

(130–200) A PIONEER OF MATERIA MEDICA. FROM AN IMAGINARY PORTRAIT

Galen (131 to 201 A.D.), the first experimental physiologist, introduced a complicated system of polypharmacy. His memory survives in the term "galenicals," a term applied to vegetable remedies prepared by infusion or decoction as distinguished from drugs prepared by chemi-

SIR CHRISTOPHER WREN
(1632–1723), FRIEND OF ROBERT BOYLE

ROBERT BOYLE
THE FOUNDER OF EXPERIMENTAL PHARMACOLOGY

cal processes. Galen, however, failed to utilize his experimental physiology in the study of the vegetable drugs he used. He just missed the discovery of pharmacodynamics. This was accomplished only a few decades after William Harvey's rediscovery of physiological experimentation.

Since this essay proposes to deal with the history of pharmacodynamics, we need not consider the achievements of pharmacognosy and empirical therapeutics of the periods that have elapsed between Galen's and Harvey's times.

According to a statement in the literature the French physician Thuillier, the older, had as early as 1630 performed the experiment of feeding seeds of rye and other cultivated grasses infected with fungi (ergot). He came to the conclusion that the eating of these infected grasses was the cause of "ignis sacer" (holy fire), as ergotism was called by the medieval physicians.

It seems that the scientific study of drug action was a direct consequence of Harvey's physiological discoveries. It originated independently in England and Switzerland. It is almost certain that the first suggestion to investigate drug action in animals by the intravenous route came from the famous London architect, Sir Christopher Wren. This suggestion of a new mode of drug administration was of vast importance because of the current belief of the seventeenth century that poisons taken by mouth cause sickness and death by reflex action from the stomach. The actual experiments were carried out by Robert Boyle and Timothy Clarke in the recently founded Royal Society of London. Robert Boyle, the pioneer physicist and chemist, was apparently the first man to perform well-controlled pharmacological experiments. He administered opium and antimony compounds to dogs intravenously and studied their effects. He showed that dogs receiving opium became somnolent and shaky, whereas the animals receiving antimony compounds vomited and subsequently died.

JOHN JACOB WEPFER
(1620 TO 1695) THE ORIGINATOR OF MODERN PHARMACOLOGICAL METHODS

Thus Boyle proved that opium and antimony are active when administered by vein, and by inference he proved that these drugs when taken by mouth act after absorption into the blood stream. Boyle and his younger contemporary Clarke, who showed that oil of tobacco injected intravenously produces emesis, carried out their pioneer pharmacological researches under the auspices of the Royal Society around 1660.

In Switzerland John S. Elsholz published in 1665 a pamphlet entitled "Clysmatica nova sive ratio qua in venam sectam medicamenta immitti possunt, addita inaudita sanguinis transfusioni"—"A New Method of Clysis by Which Drugs may be Administered into a Sectioned Vein." He reported results achieved by intravenous administration of miscellaneous remedies to animals and patients.

John Jacob Wepfer (1620 to 1695) of Schaffhausen, Switzerland, was a successful physician in his native city and devoted his spare time to the study of the effects of drugs and poisons on animals with the purpose of understanding their action, of determining their toxicity and their possible clinical usefulness. Wepfer was apparently led to his investigations by the occurrence of hemlock and other poisonings that came to his attention. He published the summary of his experiments in a very remarkable treatise: "Cicutae aquaticae historia et noxae" (1679)—"History and Toxicity of the Water Hemlock." This book is the first orderly and critical presentation of pharmacological experiments on a large scale. It contains the experimental proof that water hemlock and nux vomica are convulsant poisons. Besides vegetable drugs Wepfer used antimony, mercury and arsenic preparations in his animal experiments and sought to determine the toxicity of a number of mineral drugs. On the basis of these experiments he protested against the indiscriminate use of mercury and arsenic. Some of Wepfer's experiments are models of exactitude and care, and many of his conclusions may still be accepted. His great discovery of convulsant poisons and his studies on the action of heavy metals entitle him to a distinguished place in the history of science.

Wepfer had many students and friends who collaborated with him in his animal experiments. The most outstanding of these is another Swiss physician, John Jacob Harder, a professor at Basle, who published in his "Apiarium" the results of his numerous animal experiments (he used mollusks and all classes of vertebrates except fishes) in which he investigated the action of tobacco juice and snake venoms.

For almost a century we hear nothing of experimental pharmacology. In 1755 Menghini investigated the action of camphor on animals; in 1765 Felix Fontana performed more than four thousand animal experiments endeavoring to dis-

cover the effect of snake venom on the heart and other organs. In 1776 a young German pharmacist's apprentice, Peter John Andrew Daries, published a doctor's thesis, "On Atropa Belladonna," which is perhaps the most important pharmacological contribution of the eighteenth century. Daries, while filling a prescription of a belladonna preparation, inadvertently contaminated his eye with the drug. His vision became gradually impaired and finally he became almost blind. He went to the physician originally prescribing the drug, who washed his eye and made certain observations. His vision then gradually improved and finally returned to normal. Daries then instilled the juice of the leaves and of the fruit of belladonna into eyes of cats. By carefully controlled experiments he discovered the mydriatic (pupil-dilating) action of belladonna. He even observed that the duration of mydriasis varies directly with the size of the dose.

In 1790 a pupil of the second Monro, William Alexander, published his "De partibus corporis animalis quae viribus opii parent"—"On the Parts of the Animal Body which Obey the Power of Opium." However, his experimental technique leaves a good deal to be desired.

The action of some drugs can not be fully understood through animal experimentation if the human pathological conditions which the drug alleviates or cures can not be reproduced in animals. An excellent example of such a remedial agent is digitalis. About 150 years ago there was an old woman in Shropshire who had a secret family receipe consisting of a mixture of various herbs that possessed the power of relieving dropsy more effectively than any measures known to the best medical authorities of the time. The secret of the formula was divulged to a contemporary British physician, William Withering (1741 to 1799), who in turn discovered that there was only one among the many herbs used by this woman which was responsible for the cure of dropsy. He identified this herb as the common foxglove, known to botanists as digitalis. Withering spent the next ten years studying the effects of this one herb on patients with dropsy. At the end of this period he published a monograph on treating the sick with digitalis ("Account of the Foxglove," 1785). It contained many shrewd observations on the amount of the drug that patients require, on the changes in the pulse that accompany its action and on the symptoms which patients exhibit when they are under the full effects of the drug. There can be no doubt that the treatment of dropsy after Withering's studies became immeasurably more effective than it had been before, but Withering had no more idea of how and why foxglove cured dropsy than had the old woman of Shropshire. His method was simply a glorified form of empiricism. It is for this reason that while Withering's work may be admired, it is not a milestone of critical pharmacology.

The medical profession as a whole does not seem to have paid the slightest

FREDERICK W. A. SERTÜRNER
(1783 TO 1841) THE DISCOVERER OF MORPHINE

THE STATUE OF CAVENTOU AND PELLETIER

(FROM LEFT TO RIGHT) ON THE BOULEVARD ST. MICHAEL IN PARIS. ON THE ORIGINAL STATUE THE INSCRIPTION OF THE NAMES OF PELLETIER AND CAVENTOU ARE REVERSED

attention to the struggling science of experimental pharmacology. It chose to notice, not the heroic efforts of men like Wepfer, or Daries, but the thousands of fake or absurd "remedies" listed in the vast collections of the sixteenth and seventeenth centuries, called pharmacopoeias, dispensatories and formularies. A German pharmacopoeia of the middle of the seventeenth century contained descriptions of six thousand drugs. However, in the eighteenth and early nineteenth century methods of accurate diagnosis were introduced and a new generation of scientists, the pathologists, were able to verify diagnosis by study of the organs in post-mortem examination. Then the practice that led to the employment of these six thousand remedies appeared as sheer barbarism. A new school of critical medical scientists arose, calling themselves "Therapeutic Nihilists," who expressed disbelief in the efficacy of drugs, and when a person was ill they employed either physical therapeutic measures or nature was simply allowed to take its course.

The effects of therapeutic nihilism were on the whole salutary and challenged both science and the medical profession. While therapeutic nihilism was in full swing a number of very potent drugs, the alkaloids and glucosides, were discovered which produced pronounced effects in very small doses. Thus the objection of the therapeutic nihilist against

the inefficacy of most of the crude drugs was overcome.

We recall that the great pharmacologists of the seventeenth and eighteenth century, due to the primitive state of their chemistry, were obliged to work with crude drugs. Nevertheless, they recognized the value of animal experimentation for the understanding of drug action and the determining of drug toxicity, and the necessity of animal controls before these drugs were administered to the sick. They lacked two important things, however, which were absolutely necessary for a rapid advancement of pharmacology, *i.e.*, a thorough understanding of drug action. They lacked the fine tools of chemistry necessary to extract the active principles, the real drugs, from the crude plant products, and they lacked the refined technique of modern physiology which makes it possible to determine the exact point and mode of action of drugs in fine structures of the body.

Fortunately, in the early nineteenth century both of these weapons were introduced, and thus modern pharmacodynamics was made possible. The discovery of pure principles was inaugurated by Frederick W. A. Sertürner (1783 to 1841), a German pharmacist at Einbeck, who studied the chemistry of opium from 1805 to 1817. He not only isolated morphine in crystalline form but recognized it as a salt-forming organic base, *i.e.*, he discovered the nature of alkaloids. Pelletier and Caventou, Parisian pharmacists, continued Sertürner's researches. They isolated some of our most important and widely used alkaloids: quinine, strychnine and brucine; (from 1817 to 1820) Pelletier and Magendie (1817) isolated emetine. Pelletier and Caventou were also contributors to other fields of chemistry; among others they coined the term chlorophyll. The first synthesis of an alkaloid was carried out much later by Ladenburg, who prepared coniine (1886).

In 1830 Robiquet and Boutron discovered amygdalin, and in 1837 the two great German chemists, Liebig and Wöhler, recognized in this substance a new type of compound, the glucosides.

The physiological methods necessary for the advancement of pharmacology were introduced almost simultaneously with the isolation of pure drugs. The great French vivisectors of the early nineteenth century discovered some of the most fundamental and essential methods of physiological experimentation, and thus became the founders not only of modern physiology, but of modern pharmacodynamics as well. François Magendie (1783 to 1855) investigated the action of several pure drugs by means of his newly discovered physiological methods. His researches included the study of morphine, veratrine, brucine, piperine, and emetine and also bromides and iodides. His most important discovery in pharmacology was the determination of the point of action of strychnine. Wepfer proved that nux vomica is a convul-

FRANÇOIS MAGENDIE
PIONEER OF THE EXPERIMENTAL PHARMACOLOGY OF PURE DRUGS

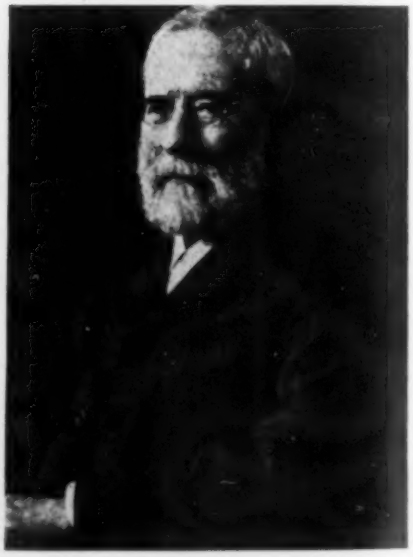
CLAUDE BERNARD
GREAT EXPERIMENTAL PHYSIOLOGIST AND PHARMACOLOGIST

sant poison. Magendie showed that the alkaloid strychnine, isolated from the crude nux vomica, is responsible for its convulsant action, and determined by brilliant experiments that the convulsions were due to stimulation of the spinal cord.

Magendie's pupil Claude Bernard (1813 to 1878), one of the greatest physiologists of all times, continued ably the pharmacologic researches of his teacher. He discovered the locus and modes of action of several opiates. He further elaborated Magendie's discovery of strychnine action by showing that the cutting of the posterior roots of the spinal nerves stopped the tetanic convulsions. Perhaps his most important contribution to pharmacology was his discovery of motor paralysis caused by injection of the arrow-poison, curare, and his experimental proof that this paralysis was brought about by the depression of the final terminations of efferent (motor) nerve fibers.

Magendie's and Bernard's pioneer work opened up the field for further researches. Their first successful followers were German pharmacologists. Rudolf Buchheim (1820 to 1879), of Dorpat, not only carried out masterly experiments on the actions of mydriatic alkaloids, thus continuing the abortive efforts of Daries, but made fundamental contributions to the knowledge of ergot, catharties and cod liver oil. Buchheim was also the first professor of pharmacology (1846 to 1879) and founded the first independent pharmacological laboratory at Dorpat University School of Medicine.

Oswald Schmiedeberg, of Strassburg (1838 to 1921), introduced methods for the study of drug action on isolated organs, particularly on the perfused frog's heart. His researches included the study of iron compounds, also mus-

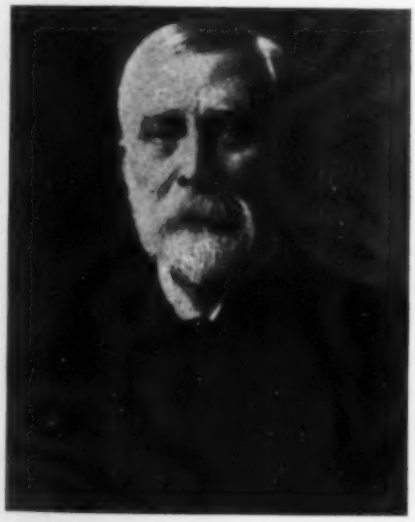


OSWALD SCHMIEDEBERG
ONE OF THE GREATEST TEACHERS OF PHARMACOLOGY

carine and digitalis. Carl Binz (1832 to 1912), of Bonn, studied the action of anesthetics, alcohol, volatile oils, quinine and arsenicals. It is interesting to recall the famous discussion between Binz and Schmiedeberg, on the mode of action of alcohol, in which Binz maintained that alcohol has a direct stimulant action, whereas Schmiedeberg asserted that alcohol has a purely depressant action and the so-called stimulant effects observed by Binz are due either to depression of the inhibitory centers in the central nervous system, or to reflex effects from the alimentary tract.

The British school of pharmacologists came into existence somewhat later, but their contributions were no less valuable. As early as 1868 Crum Brown and Fraser proved that various alkaloids possessing diverse pharmacologic actions, on combination with alkyl halides to form quaternary ammonium bases, yield substances which in almost every case paralyze motor nerve terminations in the same manner as curare. These researches proved that the addition of particular chemical groups to certain drugs may weaken or destroy or strengthen their action. Thus the first step was made towards discovering relationships between chemical constitution and pharmacologic action. Sir Thomas Richard Fraser (1841 to 1920), of Edinburgh, also discovered the cardiac action of the seeds of the African arrow poison Strophanthus and contributed to the knowledge of parasympathetic drugs.

JOHN J. ABEL
A PIONEER OF AMERICAN PHARMACOLOGY



SIR THOMAS LAUDER BRUNTON
THE DISCOVERER OF VASODILATOR DRUGS

Sir Thomas Lauder Brunton (1844 to 1916), of London, introduced nitrites as vasodilator (blood-vessel-dilating) remedies and recommended their use in hypertension and paroxysms of angina pectoris. Sir Edward Sharpey Schafer and his associates discovered, in the last decade of the nineteenth century, the

blood pressure elevating action of extracts made from the adrenal gland and from the pituitary body.

The pioneers of pharmacology in America were the great physicians and dentists who introduced ether and nitrous oxide anesthesia (Long, Wells, Jackson and Morton, 1841 to 1847). However, the founders of officially recognized pharmacology in this country are Arthur Robertson Cushny (1866 to 1926) and John Jacob Abel (1857 ——). Cushny, a pupil of Schmiedeberg, held the chair of pharmacology at the University of Michigan from 1893 to 1905. His most important contribution to pharmacology is the application of the electro-cardiogram in elucidating the action of digitalis, by which method he showed that this drug depresses the conduction of the cardiac impulse to the ventricles. Abel was appointed professor of pharmacology at the Johns Hopkins University in the same year as Cushny at Michigan. They were the first two independent professors of pharmacology in America. Abel isolated epinephrine and bufagin, and recently obtained insulin in crystalline form. His pharmacological studies on purified hormones and on phthaleins were truly epoch-making and led to important therapeutic results and diagnostic measures (kidney and liver function tests, using different phthaleins).

The trends of recent pharmacological research are along the lines of elaborating relationships between chemical structures and pharmacodynamic activity and studying the fate of the drugs in the body. They all converge toward the establishment of a strictly quantitative science of pharmacology.

THE NATURAL HISTORY OF THE BOX TURTLE

By H. A. ALLARD
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Conditions

The writer for several years has studied the behavior of the common box turtle under fairly natural conditions. It was necessary to confine them, but they were given the freedom of a good-sized enclosure embracing about 1,150 square feet, surrounded by two-foot chicken wire set into the ground about four inches. Although an overhanging ledge was made at the top, it may be stated that the box turtle shows no inclination to climb. Much of this area is covered with a dense growth of wild plants, blackberries and shrubs, affording an abundance of shade. Several pear, cherry, plum, mulberry trees and grapevines drop an abundance of fruit into this area, and a bearing papaw tree stood in the enclosure. Several tomato plants were grown here to furnish fruit for the turtles. A small bare clearing was maintained to afford a suitable situation for the laying of the eggs. Several good-sized cement basins were set into the soil and kept filled with clean water, to serve for bathing purposes and as drinking places.

The turtles have been kept in this area since the spring of 1932. The majority of the turtles were picked up in field and wood over a very wide area around Washington, D. C. Many had suffered severe injury in the past, presumably by automobiles on the roadway, for their shells showed extensive fractures, which had spontaneously healed, though in some instances leaving the carapace or the plastron sorely scarred with deep fissures.

It would appear that many box turtles in the free wandering life must find a rather scant supply of suitable food for considerable periods, as judged from the poor physical conditions of many met with. A number were thin and light and bore all the earmarks of a half-starved existence. The well-nourished and vigorous condition of others bespoke an acquaintance with better feeding grounds.

Under the conditions of the writer's confinement the turtles have thrived, and those held over from 1932 were in a far better state of health and nourishment at the end of the season of 1933.

Food

In the wild state box turtles eat anything they can find, including mushrooms, insects and their larval stages, earthworms, slugs, snails, dead animal matter, blackberries, strawberries, apples and other fruits. In the writer's enclosure, they ate with avidity sour cherries (Montmorency) falling from the trees, plums (Wild Goose), pears, grapes, mulberries, blackberries, papaws, tomatoes and ripe pokeberries (*Phytolacca decandra*) (August, September and October); the huge slug *Limax maximum* Linné; caterpillars of the catalpa sphinx; and the horn worms of tomato. One morning a number were seen feeding with much gusto on the putrefying carcass of a dead rat which cats had left within the enclosure. All these elements may be considered natural to their diet because they can be met with in a state of free wandering afield. In addition, their diet was supplemented with a more artificial menu, including remnants of the table, embracing potato, raw and cooked meat, bread, rinds of cantaloupe and watermelon, bananas, in truth any hodgepodge of table waste that was available. It may be said that they are especially fond of cantaloupe, eating the rinds to the last particle. They are scarcely less fond of blackberries and tomatoes, both of which turtles in the

field feed upon greedily. As a matter of fact a small tomato patch may sometimes suffer severely from their depredations.

The box turtle is by nature omnivorous in its inclinations, but from a close study of its feeding habits it is indicated that animal food is a first choice in its natural menu. Early in the season when the hunger impulse is keenest, earthworms, grubs and raw hamburg are fed upon voraciously. Of the vegetable foods, cantaloupe and blackberries head the list, followed closely by tomatoes. Although vegetable food is an important item in their natural diet, only the fleshy fruits and berries of the higher plants are eaten. At no time have the box turtles shown the slightest inclination to feed upon the succulent stems or leaves of plants growing around them.

Mating

Mating takes place soon after the turtles emerge from their winter hibernations in April. Although the egg-laying season extends only from early June until near the middle of July, mating may be observed throughout the entire summer, continuing at least into late September or October. The most active period of mating, however, occurs in springtime, preceding the egg-laying activities of midsummer. Cahn and Conder have pretty fully described the actual behavior of mating in their paper in *Copeia* (2) 86–88, 1932, and little comment need be made at the present time.

Digging the Egg-bed

Although many turtles are strictly aquatic creatures, the eggs of all must be laid and hatched under strictly terrestrial conditions in excavations in soil or sand made by the female. The box turtle attends to the deposition of her eggs with meticulous care. When a suitable spot is found, the female near sunset begins the laborious work of digging the egg-bed. Once the fore feet have been

Shallow concrete pool used for bathing and drinking.

THE HOME OF THE BABY TURTLES

LARGE HEAP OF LEAVES AND TRASH IN THE ENCLOSURE USED THROUGHOUT THE HEAT OF THE SUMMER FOR SIESTAS DURING THE HOTTER HOURS OF THE DAY. AFTER FEEDING, MANY REPAIRED IMMEDIATELY TO THE COOL DAMP RECESSES OF THIS PILE TO REST.

placed and digging has begun, these are never moved and the position of the body with respect to the eggs is not changed until the eggs are covered. The operation of digging is done entirely with the hind feet, and these are invariably alternated in the digging performance. The egg-bed or egg-cavity when completed is somewhat flask-shaped with a relatively narrow neck widening into the cavity proper which has been cut beneath the surface-layer. The soil is lifted and pushed upward and backward. The diameter and the depth of the cavity are limited by the length of the leg, and digging appears to continue until the feet can reach no farther in the deepening and lateral cutting operations.

The time required to complete the egg-cavity depends largely upon the character and firmness of the soil. In hard-packed soil, digging may require several hours of patient labor. In the writer's enclosure, digging has sometimes persisted between three and four hours before egg-laying began. Oftentimes pebbles and bits of soil are actually grasped by the toes to be lifted out of the cavity and placed to the rear. As the loose soil is removed and accumulates in a ridge behind, the turtle from time to time pushes it backward with the big, powerful hind feet.

When digging begins, the place is rarely changed or abandoned until the hole is completed. Three females only, of twenty-five observed digging, abandoned the work, one after a good-sized depression had been made; two very soon after beginning. There seemed to be no good reason to explain these behaviors. Pebbles and roots are very disconcerning to the creatures, for every effort seems to be made to excavate a

clean-cut egg-bed. In one instance the writer found a female with her egg-cavity completed, but a round pebble remained within which she could feel and push about with her feet but could not remove. She made repeated efforts with the usual alternations of the feet to grasp or to push the pebble out, but without success. The writer finally came to her assistance and when her leg was withdrawn, he removed the troublesome pebble with a stick, and perhaps obviated her abandonment of the hole after hours of hard labor; however, she was never aware of the beneficent deed.

Of sixty females observed, eggs were found at the point of the operation of covering in all but two instances. Whether the turtles never laid eggs, or whether they laid elsewhere, became frightened, left and lost their original orientation with respect to the true egg-activity will never be known.

So far as observed the egg-cavity has always been begun on rainless evenings. Light showers have intervened later, however, but the operation of digging, laying and covering did not cease. Whether a heavy downpour would cause the turtle to abandon her work is not known.

Extrusion of the Eggs and Covering

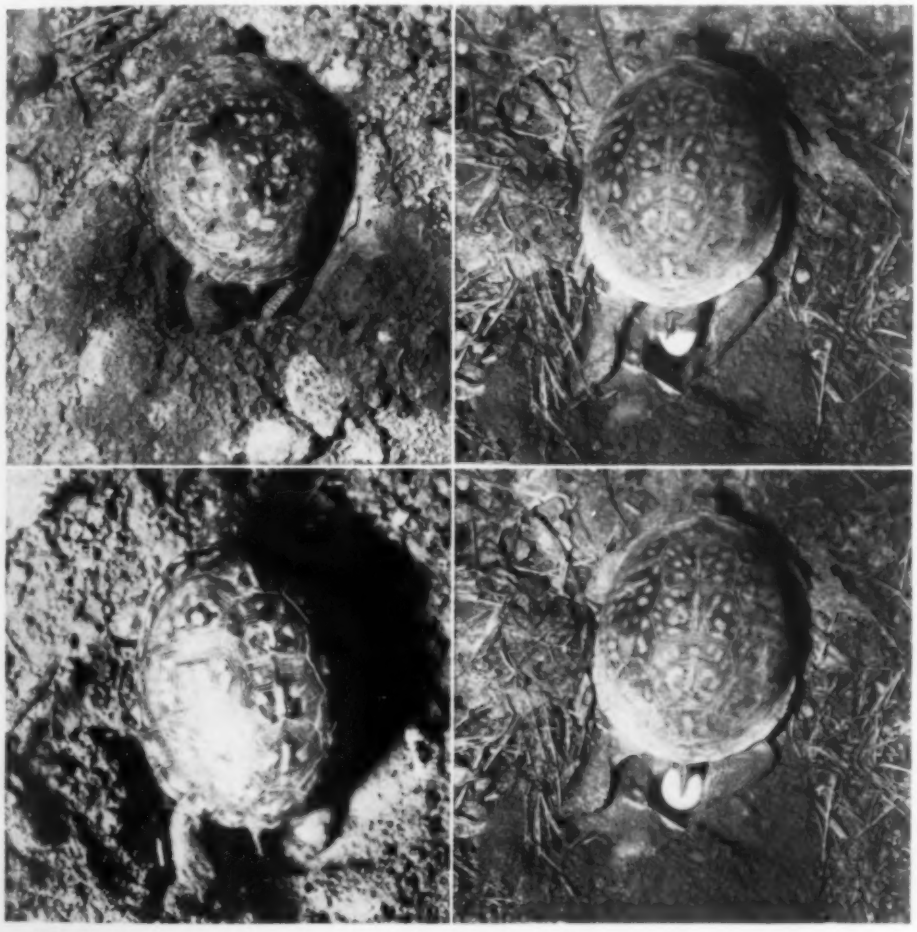
When the hole has been deepened as far as the feet can reach, the eggs one by one are dropped into the cavity. In one instance four eggs were dropped within 25 minutes; in another 6 eggs were dropped within 10 minutes; a third female dropped three eggs within five minutes. After each egg is dropped, a hind foot is inserted into the cavity and swept around as if to feel if all is well, and to place the egg as far forward as possible. If some minutes elapse before the second egg is dropped, the hind feet alternate in these movements, as in the digging operations. When the last egg has been dropped, there usually follows a brief interval of rest, with the hind foot which had been used to push and place the eggs around oftentimes left dangling into the cavity. It has been stated in the literature that the eggs are covered separately, but this procedure has not been followed in any instance in the writer's experience.

Almost invariably the first covering operation is a widely executed lateral sweep of the extended hind leg toward the hole to bring in earth. The other hind leg is then used in a similar manner. From time to time a hind foot may be inserted into the cavity to push the earth over the eggs more efficiently. From time to time wide lateral sweeps are made always with one leg to bring in the soil. Now and then, the two hind legs are extended flat and at full length backward with the toes close together, and then brought forward to the hole to sweep in earth straight from the rear where it had been pushed. It is a movement in every way comparable to that of a person crouched on the earth who would sweep in the loose sand from in front with his hands open and his fingers together. When considerable earth has been brought in upon the eggs so that to the observer they are no longer visible, or they can no longer be felt by the feet of the turtle, treading and tramping operations take place. This is always an extremely interesting and painstaking procedure and involves many nice variations in the skilful use of the toes, feet, knees and plastron in the final tamping of the soil over the eggs.

The two feet are often used in a peculiar treading operation, the knees almost or quite touching the ground. The feet are brought very close together so that the heels touch. The feet are now lifted alternately, the treading being performed practically on the tip of the toes, for the heels remain elevated. So closely are the feet brought together that she frequently steps upon her own heels, extricating her feet for each alternating tread with some difficulty. In this opera-

tion a distinct rotary motion of the feet sometimes takes place. At other times a position is taken upon the knees, so that toes, heels and knees can be combined in the treading tamping operations. At such times with the plastron held above the soil a jerky lowering of the body may be noted, as if the creature were utilizing the weight momentum of its body to supplement the simple pressing operations of the feet.

The actual covering is a long and methodically performed operation, but when it is completed there is little trace of the location of the egg-bed. In some instances the actual covering has re-



DIGGING THE NEST AND LAYING THE EGGS

UPPER LEFT. DIGGING THE EGG BED; THE HIND FEET ALONE ARE USED IN THIS PROCESS. LOWER LEFT. A SHIFT TO THE OTHER HIND LEG IS BEING MADE, FOR IN THE DIGGING OPERATIONS, THE FEET ARE INVARIABLY USED ALTERNATELY. UPPER RIGHT. SECOND EGG BEING DEPOSITED 8: 03 P. M. JULY 13, 1932. LOOSE EARTH HAS BEEN PUSHED FOR SOME DISTANCE BEHIND THE EXCAVATED EGG-BED. THE USUAL POSITION SEEMS TO BE TO RECLINE UPON ONE KNEE AS SHOWN. LOWER RIGHT. THIRD EGG JUST LEAVING THE CLOACA TO BE DEPOSITED IN THE EGG-BED AT 8: 05 P. M. JULY 13. THE SECOND EGG NO. 2 DEPOSITED AT 8:03. THESE FLASHLIGHT PHOTOGRAPHS WERE TAKEN AFTER DARK BY H. F. ALLARD, AS WELL AS THE DAYLIGHT PICTURES THAT FOLLOW.

quired nearly two hours before the creature was ready to walk away. The entire operation of digging the egg-bed, laying the eggs and subsequent covering has sometimes required four to five hours. In one instance, digging was performed from 6 to 9 P.M., a period of three hours; 6 eggs were laid from 9.10 to 9.20, a period of 10 minutes; covering was extended until 11.15, a period of 55 minutes.

The egg-cavity is about two and one-half inches in width and nearly two inches in depth. Neither the cavity nor the eggs are seen by the turtle, for these operations are usually performed in the darkness of night, and by the sense of touch of the hind feet alone. Under these circumstances the matter of proper orientation depends entirely upon keeping the position of the front legs rigidly fixed, and using these as pivots upon which to swing if need be, in making lateral reaches for soil with the hind legs. To demonstrate this point the writer inserted a stick very carefully under the plastron of a turtle which was covering and tamping the soil over its egg-bed, and gently swung it around into another position without disturbing it. The turtle continued its covering and treading operations, but over a spot now some distance from its egg-bed.

It has been stated in the literature that the box turtle usually deposits its eggs during the day (R. C. Rosenberger, "Interesting Facts about Turtles," *Forest and Stream*, Vol. 86, p. 764–765, 1916). This statement is completely at variance with all observations of the writer on this point. Of sixty laying females observed in 1932, 1933 and 1934,

TABLE I

DATA SHOWING NUMBER OF EGGS, FERTILITY, HATCHING, ETC., HIBERNATION, EMERGENCE AND OTHER SEASONAL BEHAVIORS FOR BOX TURTLES OBSERVED IN THE WRITER'S ENCLOSURE FOR THE YEARS 1932, 1933, 1934

	1932	1933	1934
Females laying	8	17	35
Eggs laid	33	77	119
Average number per female	4.1	4.5	4.1
Smallest laying	3	3	2
Largest laying	6	7	6
First laying	June 17	June 4	June 7
Last laying	July 13	July 4	July 6
Eggs laid in June	22–66.6 per cent.	69–89.5 per cent.	95–82.6 per cent.
Eggs laid in July	11–33.3 " "	8–10.4 " "	20–17.3 " "
Eggs without embryonic development	5–15.1 " "	14–18.1 " "	
Eggs destroyed by ants—fertility undetermined	4–12.1 " "	27–35.06" "	None
Fertile eggs, *i.e.*, with embryo	24–72.7 " "	36–46.7 " "	99–83.2 per cent.
Eggs hatching	19–79.1 " "	9–11.6 " "	22–18.4 " "
Eggs bad—condition indeterminable	no data	no data	20–16.8 " "
First emergence from hibernation in spring	1st week April	April 1 one adult " 2 adult " 2 seven (six adults, one 1932 yearling)	April 3 (one) adult " 6 (one) adult " 8 (seven) (six adults, one baby)
First observed to eat in spring	after April 20	no data	April 23
Last seen in autumn	Late November	Nov. 20 (one adult)	Dec. 2 (Several adults)

none began to dig the egg-cavity until late in the afternoon or near sunset, and with few exceptions the eggs were deposited near darkness or long after night had set in.

Number of Eggs Laid, and Fertility

The eggs of all turtles are consigned to earth and forgotten following the operation of covering. Hatching depends entirely upon the natural warmth of the soil. Tables I and II present data relative to the laying of the eggs and other seasonal data bearing on their activities.

TABLE II

Number of Eggs in Laying, and Number of Layings of Each, for 1932, 1933 and 1934

Eggs in laying	Number of layings		
	1932	1933	1934
2	None	None	4
3	2	3	4
4	4	6	10
5	1	5	7
6	1	2	4
7	None	1	None

Of 60 layings observed in 1932, 1933 and 1934, no turtle has laid less than two eggs, the average being 4.2 eggs. One turtle alone laid 7 eggs. Table II presents data relative to the number of eggs per laying, and the layings of each. There appears to be a correlation between the size of the eggs and the number, the smaller layings appearing to produce larger eggs. In some instances, where very large turtles laid only two or three eggs, these were exceptionally large. Actual weighings have shown that the eggs may range from 7 to 10 grams in weight. The largest eggs measured were three of the laying of July 6, 1934, these being 37 x 22; 38 x 22 and 36 x 21 mm. The smallest egg measured was a very tiny egg 16 x 13 mm., laid on June 19, 1934, together with four of normal size.

Incubation Period

The true incubation period embraces the time elapsing between the laying of the egg and the rupturing of the shell and the emergence of the turtle. The young turtle may not at once emerge from the soil, but in the writer's experience they make every effort to reach the surface as soon as possible, and probably not more than two or three days at most are spent below the surface of the soil. This delay of one to three days is of no great importance, for the period of incubation depends to a great degree upon the factor of temperature, higher temperatures within certain limits accelerating embryonic growth. Experiments made in 1933 have established the fact that the normal incubation period as observed in the field can be greatly shortened under laboratory conditions.

Box turtles emerging from the ruptured eggs.

Six eggs were removed from the soil shortly after being laid. To obviate the chance of choosing an infertile lot of eggs, one egg was selected from each of five different layings. These were placed on a sheet of clean paper resting upon moist soil in a glass dish, over which a larger glass dish of similar shape was inverted as a cover. The eggs were screened from direct light by a piece of white cotton cloth covering them. The dish was kept upon the writer's desk in

the office, where very high room temperatures were experienced throughout the summer. The eggs were examined almost daily, allowing an exchange of fresh air with that enclosed in the dish. Three of the six eggs hatched under these artificial conditions as follows:

Laid	June	10	hatched	July	30—	after	50 days.
"	"	10	"	Aug.	4—	"	55 "
"	"	11	"	Aug.	1—	"	51 "
"	"	17	No embryonic development.				
"	"	18	"	"		"	
"	July	1	"	"		"	

Unfortunately, practically all the eggs of these lots remaining in the soil were destroyed by ants or excessive wetness. However, two eggs of the lot of June 10, one of which hatched in the laboratory on August 4 after 55 days, hatched in the soil, one on September 8 or 9; another on September 10, after 90–91 days and 92 days, respectively. In this test the higher temperatures of the laboratory had reduced the out-of-doors incubation period in the soil about 42 days.

The young turtles hatched under laboratory conditions were quite as plump and vigorous as their brothers or sisters hatched under soil conditions after a longer incubation period.

In the writer's enclosure, hatching in the soil has never taken place until the first week of September, and all viable, fertile eggs had hatched with a single exception before October. The following periods of incubation have been determined.

EGGS LAID		HATCHED			
June	17, 1932	Sept.	10–11	after	85–86 days.
"	27, 1932	"	18–20	"	79–83 "
July	5, 1932	"	25–28	"	82–85 "
"	13, 1932	"	20	"	69 "
June	8, 1933	"	2–4	"	86–88 "
"	10, 1933	"	8–10	"	90–92 "
"	10, 1933	"	9–10	"	91–92 "
"	18, 1933	"	7	"	81 "
"	7, 1933	Oct.	20–21	"	104–105 "

In the colder portions of the country, this turtle becomes much less abundant. It is not a common species in New England, and appears to be very rare north of Massachusetts. The fact that a long incubation period is required for the hatching of the eggs even in the Washington region would suggest that the limiting factor in colder regions may have to do largely with the successful hatching of the eggs. In the colder portions of New England lower soil temperatures would naturally extend the incubation period. The factor of progressively advanced winter conditions, coupled with gradually extended incubation periods, would operate as efficient limitations, in a successful far northward extension of the range.

Behavior of the Young

Although the baby turtles are equipped with a tiny egg tooth, it is doubtful if this plays any very great part in rupturing the eggs. At the time the eggs are ready to hatch, the shells appear thin and soft, and subject to easy rupturing. Oftentimes the fore legs are thrust through the shell before the head emerges, and usually the active exertions of the tiny, restless turtle develop a longitudinal rent, allowing it to emerge. The creature now digs its way to the surface, or in some instances remains for a day or two below the soil, with only its head projecting above the surface. In firm clay soil, the egg cavity may not be entirely filled in the covering process, so that the eggs sometimes repose in a very loosely filled cavity.

All evidence at hand would indicate that the newly emerged turtles go into hibernation for their first winter usually without eating. As soon as they have been liberated in their enclosure they repair at once to the ground-cover of leaves and litter and remain concealed. Every effort to tempt them with tiny earthworms or grubs has given no response.

If the tiny turtles are fat and vigorous when hatched, they are likely to overwinter successfully; sickly individ-

uals usually die. Of 19–20 newly hatched turtles going into hibernation in 1932, five or six failed to over-winter. The majority, however, were in good vigor during the spring of 1933.

During the second season, the behavior of the yearlings shows a decided change. They develop wandering propensities, like the adults, feeding greedily upon all manner of food placed in the enclosure, including small earthworms, grubs, meat scraps, tomato and cantaloupe. Like the adults they are particularly fond of the latter. In late October these yearlings for the most part were able to enter their second winter fat and healthy so far as conditions could be determined.

Hibernation and Aestivation

Since the turtles are confined within an enclosure and must accept conditions as they find them, good or bad, every effort has been made to afford them suitable conditions for successful hibernation. It has been found that they are especially inclined to hibernate in low heaps of loose ground-debris, and for this reason all manner of loose weed material and fallen leaves are thrown into the enclosure, covering much of the area with an ample ground cover.

As soon as the cool nights of October are at hand the box turtles show an inclination to become sluggish, and when the cold weather of November appears, the enclosure seems suddenly deserted, so completely have they disappeared. A few individuals may remain active and venture out during warm spells even in December. At this late season, however, they evince no interest in food. A few, showing a very weak hibernating impulse, have been inclined to protect themselves with very little covering. It has been necessary deliberately to place such individuals beneath a suitable covering to avoid their freezing in severe weather. Once freezing wintry weather is at hand, the turtles are seen no more. However, they do not appear to be strictly quiescent, even in their winter beds, for an examination has revealed changes in position, and in some instances sufficient movement to enlarge a cavity around their bodies. In the normal hibernation, the turtle merely digs under the soil or ground debris three to seven or eight inches. In February or March, when warm spells are experienced a few turtles may venture forth, but the majority await the warm weather of April. Of thirty to forty turtles overwintering in 1932–33, three only died, one leaving its hibernation-bed prematurely in February having frozen to death. In every instance turtles that have died have been turtles sick or abnormal in their reactions and behavior.

During the spring of 1933, the warm weather of early April brought a number of the turtles from their hibernation beds. The majority had gone into hibernation in a big heap of loose soil and leaf debris. Even before all had actually left their beds, their heads could be seen thrust through the litter. The hibernation of the first season turtles and young turtles a few years old is similar to that of the older turtles. The tiny babies have usually secreted themselves in well-protected hollows beneath clods and a good covering of fallen leaves and weeds. Immediately after awakening from hibernation, the turtles seem little inclined to eat, and the long winter fast does not give way to a strong hunger impulse until warm spring weather has arrived.

Some observers have spoken of a characteristic aestivation behavior, but the writer's turtles, about 75 in number, have shown no definite midsummer period of inactivity or withdrawal from the heat. In May, the ground debris of the enclosure was raked together and piled in an enormous heap between six and seven feet high, and about the diameter of a large hay cock. The turtles at once began tunnelling deep into this from

THE COLOR PATTERN OF BOX TURTLES SHOWS WIDE VARIATIONS. THIS INDIVIDUAL SHOWS WIDE VARIATIONS. THIS INDIVIDUAL ORANGE YELLOW ON THE CARAPACE.

all sides and even managed to climb to the very top. This heap of cool, damp, decaying vegetable debris and humus was constantly resorted to throughout the summer, where many slept in its tunnels at night or repaired to them to rest and sleep during the heat of the day. No feature of their environment in the enclosure has seemed to satisfy them quite as much as this heap of debris. At no time, from spring until October, have the turtles shown any decided inclination to refuse food, although the hunger impulse naturally seems strongest in early summer. It may be stated, however, that pronounced changes in the liking for certain foods has been noted as the season wore on.

Intelligence, Reactions and Other Behaviors of the Box Turtle

Although the turtle in our classification ranks as a lowly reptile, in the scale of vertebrate development, it evinces a rather remarkable adaptiveness and associative memory in some respects. It is not long until the idea of food becomes associated with one's presence or with particular activities. Daily visits with food soon led them to associate the event of the personal presence with some sort of food, and a general awakening into activity of a crowd of turtles was observable. Frequent digging into their enclosure for earthworms led a number to associate this work with angle worms, and some learned to follow the turning up of the soil fearlessly almost under foot to snatch up the worms. Two large umbrella catalpa trees (*Catalpa bungei*) grew in their enclosure, each season becoming infested with enormous numbers of caterpillars of the Catalpa sphinx.

When it was found that these were eaten with avidity, the trees were often shaken or the caterpillars were beaten down to the ground. The turtles soon associated this event with the idea of acceptable food and they at once repaired to the ground beneath the trees. As many as 15 to 20 sometimes appeared to catch the crawling caterpillars. All caterpillars are not as acceptable to the turtles as the Catalpa sphinx. On one occasion the beautiful celery caterpillar was placed before them; it was intently examined by a number, but all refused to touch it. There was probably some nice sense of discrimination involved which would explain their behavior.

Our box turtles soon became fairly tame, and a number could be induced to eat pieces of bread or other food from one's hand. As soon as they became aware of one's appearance within the enclosure, they could be seen emerging from their burrows in the heap of debris to peer about.

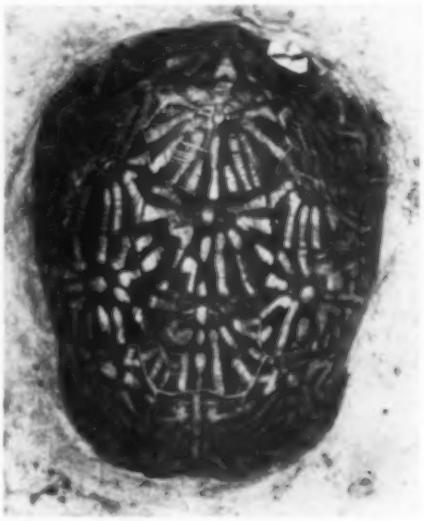
Early in the season they were voraciously fond of earthworms, which were dug up and offered to them at every opportunity. The slightest movement of a grub or worm in the soil is detected by their watchful eyes, but they are quick to detect and to recognize other food which is lifeless or does not move. The big chrysalides of the Catalpa sphinx

were readily recognized and eaten. To seize a huge earthworm or grub, the turtle follows the creature to its head, all intent with outstretched and strongly arched neck. There is a sudden snap of the jaws upon the worm, and a quick clawing at the creature with one fore foot or the other, to tear its body apart. This is the behavior of the babies as well as the adults. Such material as cantaloupe, tomatoes, cooked potatoes, bread or other bulky food is eaten by cutting out big bites with its powerful sharp-edged bony jaws and swallowing them without chewing.

Although all manner of food is eaten, the creatures appear to prefer variety in their diet; angle worms, which were greedily eaten early in the summer, were steadfastly refused later in the season. Likewise tomatoes, which at first were very inviting morsels, ultimately were almost ignored and a preference shown for blackberries and cantaloupe. Pears, plums and other fruits also had their season. So it would seem that the most suitable diet for captive box turtles should include a good variety of foods.

Shade and clean water for bathing and drinking purposes should be afforded them in an enclosure. The box turtle is very much of a terrestrial creature, but they are very fond of immersing their bodies in water, many of them remaining in their shallow pools for long periods, both day and night, now and then elevating their heads for air. Deep pools from which they can not readily escape are dangerous to the box turtle, for they can not tolerate long immersions, like water turtles, and several have come near drowning in our tests.

Although the digging of the egg-cavity is invariably performed by the hind feet, the fore feet are always used to dig the hibernation bed, and to tunnel into piles of leaf and humus debris. In the digging of the egg-bed the hind feet are also invariably used in alternation.



DISTINCTIVELY MARKED BOX TURTLE
SHOWING A WIDE DIVERGENCE FROM THE TYPE OF MARKING SHOWING IN PRECEDING FIGURE.

What, then, would a female turtle do with one hind foot? This question was answered by a female found with one hind foot amputated and long since healed. The creature dug her hole as every turtle with two feet does, strictly alternating the digging movements. However, the amputated foot could perform no actual digging and the flask-shaped cavity was unsymmetrical, the cutting being done entirely by the claws of the normal foot. In spite of this handicap the eggs were laid and covered successfully. It is probable that the turtle was even quite unaware of her deformity, since pseudesthesia would exist in the nerve endings of the severed limb.

The box turtle is usually a harmless, inoffensive creature, and can rarely be induced to snap or bite. However, several cases of vicious snapping have come to the writer's attention. On one occasion, while carrying one of these creatures near his body in a walk through the woods, it snapped its jaws upon the strap of a vasculum slung over his

shoulder and held on viciously for some minutes.

Box turtles sleep much through the day, especially during the heat of midsummer. At such times they may sleep very soundly in their tunnels in the piles of leaf and humus debris. The writer has sometimes carefully lifted them up without awakening them, so soundly have they slept; on awakening and finding themselves in the hand they appeared quite surprised and disturbed, making violent efforts to escape.

The night time is a period of inactivity and sleep for all except the females during the period of egg-laying. The coming of evening then stimulates an entirely different reaction, for they settle down to the serious work of excavating their egg-beds, laying and covering the eggs, a procedure which may persist far into the night, while their fellows sleep. This abrupt change of response to darkness is a peculiar one, for, if they are approached carefully while at work, the presence of a powerful flashlight directed upon them or the repeated blinding flash of a photographic flashlight will not seriously disturb them.

It has been shown that the females almost invariably begin the work of excavation of the egg-bed in late evening or near sunset, so that the eggs are generally laid in the darkness of night. It is evident that the turtle responds to some positive factor attending the close of the day. Is this response related to cooler temperatures, to diminishing light intensities or to an awareness of the lowered position of the sun in the western sky? The temperature factor, it seems to the writer, is too variable to establish a definite evening relationship throughout the entire egg-laying period. The writer is inclined to believe that some phase of the light factor or the position of the sun regulates this nice behavior of the females, and it would be very interesting to bring about gradually an artificial darkness for several days during the egg-laying season to determine the responses of the females. Under the particular conditions of the writer's enclosure, the females headed northward or toward points between west and north 17 times out of 25 instances observed during 1932 and 1933, or 68 per cent. In 8 instances during this period the females headed in easterly directions or toward points west and south, or 32 per cent. This seems to be a frequency more than accidental, but it may have been related to some local factor of the environment within the writer's enclosure.

The box turtles usually live peacefully together in their enclosure, but they can become very vicious fighters. In one instance two turtles eating from the same dish suddenly became enraged. Both quickly adopted a characteristic fighting attitude as they faced each other. Each lifted a front foot from the ground, and held himself as high as possible in a rearing position on the remaining three legs. At the same time they engaged in a peculiar teetering motion. With the quickness of lightning, one suddenly struck savagely at the other's head, its powerful jaws catching its adversary's beak. The turtle attacked retracted its head instantly into its shell, breaking the hold with a loud snap. The big aggressive fellow now stood high upon three legs over its enemy, one front foot uplifted, its reptile-like neck outstretched, waiting motionless with savage ferocity in its expression for it to protrude its head again. This turtle seemed well aware of danger, and merely waited until its vicious enemy tired of the fray and repaired to the food again.

Disease, Enemies, Etc.

The general health of turtles appears to be largely a matter of proper feeding. Many turtles in the field probably want for food much of the time, and some have been found thin and light, indicating a

half-starved existence. Such individuals have gained in general health, weight and vigor with better feeding.

The general health of the turtles carried over from 1932, around 60 in number, was far better during the seasons of 1933 and 1934 because they were afforded a more generous and varied diet.

Turtles are sometimes picked up in the field with one eye destroyed; some have been found with a foot missing. The development of peculiar swellings localized upon the face and neck, sometimes on one, sometimes on both sides, is a rather common affliction. The swelling sometimes greatly enlarges and closes the eye, or makes the retraction of the head into the shell difficult or impossible. This trouble may affect the most vigorous turtles and it usually appears shortly after the hibernation awakening. This swelling appears to be purely superficial, involving the fleshy parts of the face and neck, but the affected turtles became profoundly ill and lethargic out of all proportion to the seemingly slight, local nature of the swelling. As soon as any swelling of the face is evident, the turtle's behavior changes. It becomes lethargic, spends much of its time in the water, both night and day, sometimes remaining in the water for days. As the swelling enlarges, the eyes are closed, the head becomes misshapen and the appetite fails. Although this condition may persist for weeks, a gradual subsidence of the swelling usually follows, or in many instances a transition of the generalized enlargement into a more restricted and localized elongated outgrowth which projects from the face. Invariably this particular form is scratched off, and has been left upon the soil as a big, fleshy elongated hump. The clean, superficial scar remaining soon heals, and at once the normal behavior of the turtle is resumed. Although this trouble has been rather frequently observed, no turtle has died as a result, and usually by autumn none show such swellings. Some have seemed such hopeless cases, with the eyes tightly closed, as a result of these swellings around the face that it was feared recovery would be impossible. In due time, however, such individuals recovered and attained perfect health. It is rather puzzling why such afflicted individuals repair so consistently to water, as if they were in a state of fever. Fever, however, in a cold-blooded creature approximating more or less the temperature of the environment can not be of the same order as our own. Yet it is possible that a feverish condition somewhat above that of the environment obtains, even though the normal body temperature of the turtle may vary widely, depending upon environment.

These swellings do not seem to be of the nature of simple abscesses, and they do not rupture into open sores. There is some reason to believe that parasitism of some kind may account for their presence.

A condition resembling cold and perhaps pneumonia not frequently affects turtles, the nasal passages discharging and sometimes with foam about the mouth. Affected turtles become lethargic and disinclined to eat; recovery usually ensues.

In several instances a peculiar cloacal elongation and eversion has affected some turtles. The cloaca becomes so protruded that the posterior lobe of the plastron squeezes upon it. This is a very serious ailment, for the everted cloaca becomes infected and infested with flesh-eating larvae, and the turtle dies. The cause of this trouble is obscure. Post-mortem examination has revealed a strictly local condition as far as could be seen, associated with the cloaca alone.

Box turtles, like all other invertebrates, are infected with internal parasites. Some have been found with heavy ascarid infestation, these crawling in

numbers from the cloaca. However, a light infestation appears to cause no serious symptoms; although they may represent a normal association with the turtles, the latter are undoubtedly better off without than with them. It is known that the troublesome "chigger" occurs on the box turtle, but probably it is not more worried than human beings by this pest. The eggs at every stage of development, before hatching, are often cleaned out by tiny ants, one being the species *Solenopsis molesta* Say,[1] and the writer is inclined to believe this is the species causing the usual destruction. The eggs are also destroyed by crows and by some dogs, which can locate them by smell. The great scourge in the box turtle's life is fire sweeping over its domains, and the automobile with drivers who deliberately or carelessly crush them on the highways. The death rate on the highways in spring during the restless mating season is very high, and can not but greatly decimate their ranks if persisted in year after year. Some well-known scientists have told me that they always kill them because they eat their tomatoes, but it is a deplorable attitude toward life and nature to give the poor reptiles, harmless and even positively beneficial, no chance to dwell among us. Some scientists have told the writer that the extermination of life, whether it be plant or animal, means nothing if it is done in the progress of the civilization of man. In its higher aspects, however, the true progress of man is not a relationship alone with mechanical appliances and with the materialism of the universe turned into money values. The higher progress has to do with spiritual values dependent upon elements of truth, art and religion gained from the universe. Genuine progress is not one of untrammeled and careless destruction of the original environment which man has found, but one of thoughtful preservation so far as possible of all those things of interest and of utility which occur around us. In this mood the poor box turtle has a just claim on our sympathies and deserves our consideration and protection.

[1] Identified by Dr. Wm. M. Mann, of Washington, D. C.

"MICROMEN" OF THE SOIL

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WHEN a man undertakes to grow a crop of corn, cotton, tobacco or what-not, he either knowingly or more probably unknowingly requires the services of many, many laborers. He may hire some one to plough and harrow the ground or he may do that himself. Later he plants the seed and from time to time cultivates the crop.

Let us suppose that the ploughing turns under some plant remains, cotton stalks, corn stubble, grass or weeds. The farmer tells his neighbor that this organic material will enrich the soil and aid in his next crop. He may add also some stable manure or may plough under a cover crop.

While the farmer is thus preparing and planting his soil, he is, for the most part unwittingly, letting a series of contracts. It is true that these contracts are not drawn up according to the latest legal procedure, but they are binding nevertheless. In fact they are as binding as the famous laws of the Medes and Persians.

We refer to the contracts let with the large number of different subdivisions of that great fraternity, "The Amalgamated and Confederated Order of 'Micromen' of the Soil." This great fraternity comprises all the bacterial workers who carry on chemico-biological changes in the soil. In this paper we shall mention only the bacterial fraternities and not attempt to include other important groups, as the fungi, actinomyces, protozoa, algae and other lowly denizens of the soil.

Let us refer to a number of the principal labor unions that make up this great fraternity of micromen.

First, there are the day laborers that do the rather ordinary work of tearing apart the molecules of plant and animal remains. These might be referred to as wrecking crews, and while many bacteria can break down numbers of different substances, there are certain local labor units whose contracts call for only certain types of labor.

Then there are the highly skilled or specialized workers which carry on the more specialized phases of the soil work.

Let us look first at the laborer class of wrecking crews. Here we have the bacteria of general decay, many of which are rod-shaped spore formers. Many are rod-shaped non-sporing bacteria, and there are also spherical bacteria. The main reason why these bacteria of general decay carry on is because these micromen get their food in this way. They can not eat unless they work, and in part at least their work consists of eating. A microman for instance, of the shape but not nearly the size of a hot dog, turns loose out of his body certain enzymes which digest or make soluble organic substances which the microman then absorbs and utilizes in building his body. We have been frequently told in these days of increasing social complexity that "No man liveth unto himself," a well-known biblical statement. Here let us notice that rarely does a microman live unto himself. He ordinarily absorbs soluble food that was digested by enzymes excreted by his ancestors that lived ten or more generations in the past, perhaps two to ten hours before. These micromen may come into existence, work faithfully, grow and reproduce within the short space of thirty minutes.

Even the micromen of the lower orders in the labor unions require very definite working conditions; in other words, they work under a code not unlike that of the

NRA. If the soil is too cold they lie in bed and will not work. If the air is too poor they demand improved ventilation before they will work. If the number of hydrogen-ions is excessive in their locality, they likewise refuse to budge. No amount of cajoling on the part of the farmer is here of avail; he simply must live up to his part of the contract, namely, that working conditions shall reach a minimum set of requirements before any work is done.

We have spoken of proper ventilation. That is all very well for some of the unions. Others care little about ventilation and work either with or without an available supply of oxygen, while, strangely perhaps, there are numbers of local unions who just despise a well-ventilated soil. Their desires are not satisfied until all free oxygen is removed, and in fact some seem to be actually injured by free oxygen.

In this connection let us see how different unions are willing and ready to cooperate. One that demands air, an aerobic group, consumes the oxygen available, and thus helps his brother craftsmen, the anaerobes, to live and labor.

Many human laborers are insistent in their demands that their food contain certain meats, vegetables, fruits or desserts. For instance, cases have been known where human workers have refused to continue their labors until food agreeable to their tastes was furnished. We have a closely similar situation with the micromen. If considerable straw is present in the soil, the farmer hopes to see it decomposed and expects the bacteria and other soil organisms to carry out its decomposition.

A number of guilds of these tiny craftsmen are able to attack cellulose. Some aerobic rods, certain anaerobic species and at least one Spirochaete work readily and in the case of the latter organism solely on cellulose. However, these organisms will do this job only provided their working conditions are met. They simply demand a source of nitrogen in their food. It is true they may not be insistent on T-bone steaks, as their human counterparts, but have nitrogenous substances they will or they promptly go on strike.

A friend was in the habit of feeding some micromen a diet of shredded filter paper and certain mineral salts, including nitrogenous salts. These little workers rapidly destroyed the filter paper added to the pots in which the soil was kept and became exceedingly numerous. However, when an additional amount of filter paper was added, if the nitrogen supply was forgotten, the little fellows promptly quit working. How could you expect them to work when they could not build their bodies out of the food that was furnished, since to make protoplasm, nitrogen was necessary as well as the elements carbon, hydrogen and oxygen present in the filter paper.

Interestingly enough, the cellulose, in this case filter paper, even if additional nitrogen was not added would slowly but very slowly disappear. You suppose that some of these cellulose attacking microworkers decided to break their contracts? Decidedly not, but as some of their brethren died, they were able to digest the dead bodies of their brother workers with the help of other bacteria of decay, and thus carry on slowly. Let us not consider these micromen cannibals, for they do not kill their brothers for food, but if some of the craft have died from other causes, then the case is different.

Let us now consider briefly the activities of some of the highly skilled or more special guilds of this great fraternity in the soil. We do not expect carpenters to begin the superstructure on a house until the masons have completed the foundation. Neither must we expect a group of workers like the nitrifying bacteria to begin their work until their friends, the bacteria of decay, have brought their work to completion and

changed the nitrogen originally present in organic combination to ammonia.

We have two separate unions of the nitrifying bacteria. One group must have ammonium salts which they oxidize to nitrites and in this way obtain the energy needed to build their bodies from carbon dioxide and mineral salts. They will consume no organic food whatever. Just as soon as these nitrite formers have changed the ammonia to nitrites, the nitrate formers jump in on the job and convert the nitrites to nitrates.

Now the farmer is getting results, for the ammonium salts in the soil and the nitrates are taken up by his crop plants, and these crops grow. What has the farmer done, and just how has he let the contract to the micromen? He has stirred the soil and increased the ventilation, giving his bacteria the oxygen so many of them demand; he has furnished food and minerals which all of them need. If the soil had too many free hydrogen-ions he may have tied up a lot of them so they could do no more mischief, by the addition of lime. All in all, while the farmer probably does not know it, he is satisfying the demands of the labor unions to which these microworkers belong.

Another of the special guilds of microworkers has specialized in a different direction. This group has learned of a better way to get along than any of its fellows. The free-living nitrogen fixers, called by their human admirers Azotobacter and Clostridium, do not have to depend on the organic or inorganic material of the soil for their nitrogen. If protein or peptone is handy, they will eat it of course, but they do not require it. In fact this special group of micromen show evidence of advanced ability, ability not possessed by not only their fellow craftsmen of the soil, but not possessed by the higher plants or animals, even man.

Although the air we breathe is about four-fifths nitrogen we can not use this nitrogen, neither can the green plants. In the nitrogen-fixing bacteria we have a few groups of micromen who know how to get their nitrogen from this inexhaustible source. We might suppose that these microworkers, having learned how to get their nitrogen from the air, would be able to grow without organic food, but not so. They are still dependent on sugars or substances closely akin to sugars for their energy requirements and disdain to touch celluloses and lignins.

Azotobacter happens to be an aerobe, while Clostridium is an anaerobe. Hence it happens that not infrequently these two groups are found growing in partnership, the Azotobacter developing until the oxygen is used up, and then the process of nitrogen fixation being continued by the anaerobe, Clostridium.

The Azotobacter cells usually quit when the hydrogen-ion concentration reaches an acidity referred to as pH 6.0 and refuse to grow under more acid conditions. Just at present experimental work is under way to try to learn just what grievance the micromen have. Are they disturbed by the hydrogen-ions present or do they object for some other reason, since we know that occasionally they do work under more acid conditions?

It may be that the farmer decides to plant a leguminous crop to help enrich his soil. This attempt will avail him nothing unless certain humble nitrogen-fixing bacteria are present and working in his soil. To be sure he has the right ones available he may import labor to his liking, by inoculating his seed.

The nitrogen-fixers that live on legume roots in the soil, like their other associates of the soil, belong to a number, perhaps a dozen or more of different unions. One will grow only on soybeans,

for instance, another will attack vetches and garden peas, another will grow on alfalfa and sweet clover and so on.

These nitrogen-fixers attack the roots of the leguminous plant and the plant responds by growing a nodule in which the micromen live and labor. We may consider these bacteria as parasitic on the roots because they demand and get organic food from the legume plant. However, the legume is able to fight back and take from the micromen a good deal of combined nitrogen, so the parasitized legume plant is really the gainer after all.

Another highly specialized group of microworkers include the so-called sulfur bacteria. Some of these oxidize hydrogen sulfide formed by the bacteria of decay to sulfur and some change sulfur to sulfuric acid. In a few cases the farmer has been instructed to import sulfur bacteria, but this is largely unnecessary as enough of them are usually already there waiting for a chance to do their share. Now what do you suppose becomes of the sulfuric acid? Of course, if any happens to come in contact with a piece of filter paper or a similar piece of organic substance, it may have the same effect as when sulfuric acid is accidentally spilled on your suit. You know it just simply ruins good clothes to have sulfuric acid drop on them; they never look the same afterwards. In the soil there are bases available, and as soon as the sulfuric acid is formed, it unites with them, forming sulfates which may be taken up by the plants.

Without these micromen of the soil, together with the fungi, Actinomyces, etc., which we have not space to include in this paper, dead matter in the soil would never decay, elements would remain tied up for many years, and the world would be in a bad way indeed. For this reason we are in absolute need of the valuable services rendered by these largely unseen and unsung heroes of the soil.

Let us not conclude this paper without a brief mention of the gangsters or racketeers among the micromen, for here we have another counterpart of a phase of modern anti-social activities among these lowly microbes. In all soil there are lurking sinister forces which may cause considerable damage if certain gangs of the racketeering micromen can just get a chance to work. We refer to a group of bacteria known as denitrifiers. They attack the nitrates of the soil and destroy them, giving off nitrogen in the form of a gas and it is then lost from the soil.

Another thing about these marauders is that they sometimes cooperate with other ordinarily respectable micromen in carrying out their mischief. For instance, *Bacillus coli* may break down nitrates to nitrites and along comes *B. denitrificans* and turns the nitrites into free nitrogen and then it is lost.

How can the farmer protect himself against this band of outlaws? He can see to it that the conditions in the soil are such that these destroyers can not work. Good aeration is one of the easiest ways of preventing their action and this may be obtained by cultivation and drainage.

HOW FAR CAN I SEE?

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THE question which forms the title of this paper is one of the most important of all the questions which the aviator puts to the meteorologist. Upon the correctness of the answer hangs the safety of the pilot and of his passengers, and the delivery of valuable cargoes of mail and perishable goods.

The present-day meteorologist is able to give answers of remarkable precision to many of the questions asked by the public. His occasional failures, once a favorite theme of the comic press, are now realized to be due to insufficient data rather than to guessing. The accuracy and range of his predictions are being extended rapidly by the use of new knowledge about the atmosphere we live in. It is the more surprising that the "seeing," the clearness or obscurity of the lower air, continues to be measured, or rather estimated, in an entirely primitive manner. We shall find later that there are reasons for this apparent lack of progress.

In weather jargon, the distance we can see on any given occasion is called the "visibility." Not, be it noted, the clearness of the seeing, but the distance. Purists may smile if they like, or they may feel as Professor Brander Matthews did when he discovered (not in a Service Club paper, but in an electrical journal) the "separately excited booster." Others, more accustomed to the strange verbal progeny of applied science, have only to remember that when we speak of *the* visibility we refer to the *range of vision*, no matter what the dictionary may say.

The readers of THE SCIENTIFIC MONTHLY will be well aware that the atmosphere is composed largely of nitrogen and oxygen, with smaller but easily measurable amounts of carbon dioxide, argon and other gases. These gases are remarkably transparent; it may be calculated that in an atmosphere containing nothing else, an aviator could make out a mountain at least 250 miles away. The fact that such great visibilities seldom occur suggests immediately that the air must be "full of a number of things" not mentioned in our list of gases.

Always, of course, there is water-vapor. Now water-vapor is also very transparent to the kind of radiant energy which our eyes recognize as light, as long as it has no opportunity to condense into little drops.

Rather larger than the air-molecules are the so-called "nuclei," which seem to consist sometimes of groups of gas molecules, sometimes of tiny particles of salt from the sea spray, and sometimes —especially near cities—of products of combustion. When there are many of these, with a little water collected on each one, the air is hazy.

Now these haze-particles form excellent pegs, so to speak, on which to hang water-vapor molecules. Most of them are hygroscopic, which good Greek scholars will take to mean that they watch out for water molecules and, having found one, will not let it go. When one of these haze particles has accumulated enough water to make it about 1/5,000 of an inch in diameter, it begins to act differently towards light, and we call it a fog droplet. For this diameter is rather larger than a wave of visible light, whereas the haze particle is about as big as a wave or somewhat smaller.

The effect of particles of different sizes on light waves is a subject which bristles with mathematics. An analogy

which has often been used points to the rows of piles which support a pier over the ocean. Suppose these piles are two feet in diameter; then the little ripples, a few inches long, on a calm day, will be reflected from their broad surfaces; but the big combers will wash right through, though their height may be diminished. This is rather obvious. But if you watch very carefully, you will see secondary waves being sent out from the piles in all directions. In a similar way, the particle which is large in respect to the waves will treat the various colors (wave-lengths) alike. This is why a fog looks white. But the tiny haze particle scatters the short waves of blue light more than the longer waves of red light, and the result is that a haze looks blue when you look *at* it, but makes a light—such as the setting sun—appear reddish when seen *through* it.

The reader will naturally object, "But when I see a distant mountain through hazy air, it looks blue." This objection brings us to a very important point, which is vital to our subject.

When we see a distant lamp at night, we see it by virtue of the light which gets through the intervening mass of air-molecules, haze-particles or fog-droplets to the pupil of the eye. If there are too many of them, we can not see the light. But when we see the "blue of the distant hills," we deceive ourselves; what we really see is the blue of the air between the hills and our eyes. As our gaze travels from hill to hill into the distance, a point is reached where we can not quite be sure—is it a hill, or the sky beyond? The air-light at this point has come to be nearly (about 98 per cent.) as bright as the horizon-sky, which latter is, of course, all the air-light between us and empty space.

The difference between the two cases can perhaps be expressed by saying that the distant light at night vanishes because of the light which the air takes away; the distant hill in the daytime, because of the light which the air places in the way. I believe that this simple way of putting it has a true scientific standing, in that it leaves out nothing essential.

Now if it is haze we are looking at, more of the blue light than of the red is scattered into our eyes, making the distant hills appear blue; while if we are looking through a great thickness of it at a distant lamp, the blue is scattered in all directions more than the red, so that the light which does get through is reddish.

With this in mind we can define the daytime visibility as the distance at which an object becomes so nearly as bright as its background that we can no longer see its outline. It was suggested above that this takes place when one is about 98 per cent. as bright as the other. Put in another way, the *contrast* between object and background is then about 2 per cent. It is one of the properties of the human eye that it can not distinguish a contrast less than this. If we could devise an artificial eye which should be super-sensitive to small brightness differences, and train it on the horizon, it would be able to see distant objects farther and farther, till the curve of the earth got in the way.[1]

It is not immediately obvious that this is so. It would be natural to think that if, on a certain day, a wooded hill 23 miles away were 90 per cent. as bright as the horizon, and a similar hill 30 miles away 95 per cent. as bright (a case which might occur), then a hill 37 miles away would be 100 per cent. as bright. But that is not what happens. Actually the 37-mile hill would be 97½ per cent. as bright as the horizon, and therefore just within the range of vision; a hill at 46 miles, 99 per cent.; at 69 miles, $99\frac{9}{10}$ per cent. And 100 per cent.? Never; at least as long as the hill remains a real

[1] This is true in clean air or in haze. It is probably not true in fog (certainly not in dense fog) for reasons which can not be discussed here.

terrestrial elevation, standing on the ground, with air behind it again. The series of percentages which I have written down is much like the series of numbers we obtain if we add $\frac{1}{4}$ to $\frac{1}{2}$ and $\frac{1}{8}$ to the sum and $\frac{1}{16}$ to the new sum and so on—always getting closer to 1 but never reaching it. It is rather like pumping the air out of a globe, and removing, say, $\frac{7}{8}$ of the air still in the globe every minute. After hours of this, there will still be a little air left.

The fact that I was able to write down the above percentages is evidence that we know the law connecting the apparent brightness of an object and its distance. The law is a very simple one, and rather like the law which connects the weight of a healthy child with its age; but it was not explicitly stated and proved till 1924.

The obscuring power of the atmosphere at any given time and place is expressed by a number known as the extinction coefficient. When a little algebra is done with the law referred to above, it is found that the extinction coefficient is equal to a constant divided by the visibility of a dark object against the horizon sky. The importance of this is that it demonstrates that the visibility of such an object really is a measure of the obscuring power of the atmosphere, or at least an approximate one.

The law regarding the visibility of lights at night is not quite so simple, for it involves the candle-power of the light. However, if this is determined, any given value of the extinction coefficient corresponds to some unique distance of visibility.

The actual measurement, or rather estimation, of the visibility is a very simple process. The observer looks at a previously chosen set of objects at various standard distances, beginning with the nearest, and notes which one is just visible. "Just visible" is generally agreed to mean that the shape of the object can be distinguished—not merely that something is there. The visibility is then the distance of this last visible object.[2] At night, lights at various distances are observed, and the distance of the farthest one which can be seen is recorded.

This procedure can be highly satisfactory provided: (1) that the observer has normal eyesight; (2) that a sufficient number of objects and lights are available at suitable distances; (3) that the objects are fairly dark in color and are seen against the sky; (4) that they appear approximately equal in size; (5) that the lights are of the proper candle power (the more distant ones should be much brighter); and (6) that there are no important sources of artificial obscurity, such as factory towns, between the observer and any of the marks.

The reader will note that we have here a series of "ifs" almost sufficient to afford material for a parody on Mr. Kipling. It is fairly certain that there is no meteorological station on earth at which all these conditions can be satisfied. Consequently, meteorologists have looked about for an instrument which will enable them to measure the visibility even if only a very small number of objects and lights is forthcoming.

There is no such instrument at present which is entirely satisfactory for meteorological use. All but one—as far as I am aware—are limited either to day or night use; the one exception is prohibitive in cost. Several of them require observers trained in optical measurements—a fatal defect in routine work. One or two instruments which seem promising in a restricted way have failed, somehow, to be generally adopted.

The best we can do at present is to choose our objects carefully, having them as dark as possible, always against the sky, and of dimensions proportionate

[2] This is the American practice. In Europe and elsewhere the convention is that the visibility is the distance of the first standard object which can not be seen. We can only assume that there must be a hidden reason for this.

to their distance; and to choose our lights with due regard to their candle-power. Very great improvement in these respects could be made in current practice, and no doubt will be made as the underlying principles become more widely known.

The visibility is related in a general way to the weather, the time of day and the season of the year. The actual form of the variation is very different in different parts of the world, and there exists a tremendous literature on the subject, chiefly in papers on regional climatology. In the space available we can indicate only a few general principles.

In some places, such as central Europe and parts of eastern North America, the visibility is generally greater in summer than in winter. In others, such as the region of the Grand Banks, the reverse is true. On the great plains of North America, the seasonal variation is not very well marked, though the very greatest visibilities occur in winter, when the cold air, overlying the snow-covered ground, contains very little moisture and almost no dust.

Visibility bad enough to be a danger to aviation is most frequently due to the presence of fog. It is a general rule that in maritime climates fog is most frequent in the summer, in continental climates in the winter. This effect may occasionally be so marked that an air-route which normally lies along a coast may have to be moved a short distance inland during the summer months; or a terminal airport at a coast city may have to be provided with a convenient auxiliary landing field at some distance from the sea.

The visibility is usually greater in the afternoon than in the morning. This is because the heat of the sun, warming the hazy layers of air nearest the ground, causes them to ascend, and the resulting stirring-up of the air in the first mile or so distributes the haze particles through a larger volume. With the coming of night the mixing ceases, and the air again begins to stratify, with most of the haze at the bottom. A strong and persistent wind, however, interrupts this normal nocturnal process, while a heavily overcast sky and calm weather during the day prevents the air being stirred up. At most seasons and in nearly all localities, fog is most frequent during the early morning also, a fact which shows up in statistical summaries of visibility observations.

The reader has no doubt recently become aware that the temperate zones are a sort of battleground, the scene of constant warfare between masses of tropical air from nearer the equator and masses of polar air from higher latitudes. The changing fortunes of these mighty antagonists result in this part of the world being covered alternately by air of the two kinds. Our present interest in this lies in the fact that the polar air is usually very much clearer than the tropical, especially in winter and over the continents, partly because it is very much drier, and partly because of its origin over clean fields of snow and ice. In the central and midwestern states and the central provinces of Canada, it is not uncommon for the visibility to increase from two or three miles to fifty or a hundred miles in the space of an hour or so, as the advancing front of the polar air pushes back the air from the tropics. Even when this atmospheric victory is not accompanied by thunder and rain, the great and sudden increase in the visibility will tell the watchful observer that the battle has been won.

The meteorologist's knowledge of the movements of these air-masses, gained by means of his world-wide "intelligence department" and embodied in the daily weather maps, renders more and more trustworthy his answer to such a specific question as "How far shall I be able to see over western Pennsylvania this afternoon?"

COSMIC RAY BURST PHENOMENA

By GORDON S. BROWN

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For almost three decades the mystery of the origin and nature of cosmic rays has presented a puzzle of the first magnitude. During recent years, however, there has been a great deal of activity in the work of unraveling this mystery, and many data relating to it have been collected. It is apparent to those familiar with this field of research that the energy of the radiation as received is too small for it to be of commercial importance of itself. But the processes involved impart far greater specific energies to corpuscles than any others yet known, indicating that if we ever become able to understand and control the mechanisms involved in cosmic-ray phenomena and learn how to reproduce them we may make available a new and potent source of energy.

The only known method of detecting cosmic rays is through the ionization which they produce in gases. In fact, a good present-day definition of a cosmic ray would define it as "a radiation penetrating the earth's atmosphere, which is only detectable in terms of the ionization which it produces in gases." Three types of cosmic-ray measuring apparatus have been evolved which depend on this ionizing property of the rays for their action, namely, the ionization chamber, which measures the rate of production of ions, the Geiger-Müller counter, which uses the ionization to initiate an electrical discharge and counts rays or groups of rays, and the cloud expansion chamber, which makes evident the paths of the rays by the condensation of droplets of liquid on the ions formed by the corpuscles. The devices employed to measure the ionization-currents in the early ionization chambers were relatively insensitive and gave indication only of average values of the rate of ionization over considerable periods of time. As more sensitive types of apparatus were developed it became possible to investigate more in detail the manner of production of the ionization.

Hoffman, working in 1928 with a large and sensitive apparatus, noticed that occasionally there occurred very large momentary increases in the rate of production of ions. These sudden increases he called "Stösse." The English term given to the same phenomenon is "burst." The ionization is produced by ionizing rays crossing the chamber, and because these rays occur in a more or less random manner there will result statistical fluctuations in the rate of ion production. For this reason there was at first some doubt as to the reality of these bursts. However, for a random distribution in time of the rays, there exists a calculable relation between frequency and magnitude of statistical fluctuations and it can easily be shown that the observed frequency of occurrence of bursts of large size is very much greater than would be expected if they were all due to statistical variations. Hence, there seems to be no doubt that the bursts are a manifestation of some real phenomenon, perhaps different from that which produces the usual type of average cosmic-ray ionization. All experimenters working with sensitive ionization-chamber apparatus have since found these bursts. They have also been photographed in Wilson cloud-expansion chambers, and detected with Geiger-Müller counters.

Early in the spring of 1934 the first of a new series of large cosmic-ray intensity meters was completed at the University of Chicago. These instruments were designed and constructed under the

direction of Professor A. H. Compton of that institution and sponsored by the Carnegie Institution of Washington.

The spherical ionization chamber of this instrument has a diameter of fourteen inches and is filled with very pure argon at fifty atmospheres pressure. Argon gives a better yield of ionization than lighter gases because the heavier atoms form better targets for the rays. The yield also goes up very nearly linearly with pressure for pure argon. The current measuring device is a Lindemann electrometer, which is arranged to record photographically the rate of production of ions continuously on a moving film. The instrument is also provided with mechanisms which compensate for pressure and temperature fluctuations, and the chamber is shielded against local radioactive rays by a concentric layer of lead shot of twelve centimeters effective thickness. The writer, with Henry A. Rahmel and Ralph D. Bennett, of the Massachusetts Institute of Technology, took the first meter to be completed to Colorado for a field test at different elevations.[1] The instrument was operated for about two hundred hours at each of three elevations; namely, 5,300, 10,600, and 14,100 feet above sea level. The resulting records, together with another series for about 200 hours observation made for us at Chicago by Drs. R. L. Doan and E. O. Wollan, were examined for "bursts." The magnitude and frequency of the occurrence of these "bursts" or sudden increases in ionization were recorded.

At about the same time, Drs. C. G. and D. D. Montgomery[2] took another apparatus to Pike's Peak and made a similar series of observations. Their apparatus was designed primarily for the study of bursts and was operated at a higher sensitivity for this purpose than was ours. They also studied the effect of measured amounts of lead placed above their ionization chamber.

Any conclusions which might be drawn from these observations concerning burst phenomena depend on the result of a statistical analysis of the data. For a very satisfactory analysis of this sort we feel that a much larger number of data would be necessary. However, the following trends were indicated:

(1) The frequency of bursts of any given number of ions increases with elevation at somewhere near the same rate as the total average rate of production of ions.

(2) The magnitude of the largest burst likely to be observed at any given elevation increases somewhat more rapidly with elevation than the average rate of production of ions. The largest burst in our Chicago records amounted to about 150 million ions, whereas the largest observed at 14,100 feet elevation (the summit of Mt. Evans) exceeded the range of the instrument and amounted to more than a billion ions. The relative rates of ion production at the two places is in the ratio of about 1 to 3.

(3) The bursts included in the study contribute less than one per cent. of the total ionization. However, this study included only bursts of relatively large sizes. The possibility that all the ionization comes from bursts is therefore not excluded because the contribution of the smaller and much more frequent bursts is at present unknown.

(4) The physical dimensions of the ionization chambers have not yet exceeded the physical dimensions of the bursts. As instruments have increased in size the observed number of ions set free in the average burst has also increased.

There remain many interesting fields for speculation as well as for experiment. For instance, the mechanism of the bursts is not yet understood. If the release of the ions in a burst results from

[1] R. D. Bennett, G. S. Brown, H. A. Rahmel, *Phys. Rev.*, 47: 437, 1935.

[2] C. G. Montgomery and D. D. Montgomery, *Phys. Rev.*, 47: 429, 1935.

the simultaneous passage through the chamber of many rays of the kind ordinarily seen in cloud chambers, then our largest burst must have been the result of between five and ten thousand of these rays. Such a large number of rays can not have come from any single atom unless the constituent parts of an atom are much more numerous than has been supposed. Nor is it to be expected on the basis of known facts of interactions between rays and nuclei that several atoms would cooperate to produce such a large number of rays. There is of course the possibility that a reversal of the process of conversion of mass into energy might be taking place. Also there has been some indication recently of the occasional occurrence in Wilson cloud chambers of particles which produce very large numbers of ions in a small region. A particle of this type might account for the very great numbers of ions released.

The energy released in our largest burst totals up to a surprisingly large value. Allowing 30 electron volts per ion pair we get some 3×10^{10} electron volts of energy manifest within the chamber. The absorbing power of the argon is something less than one fiftieth part of that of the shield, so that if we assume that these rays have penetrated any considerable part of the shield the total energy of the burst totals up to some 10^{12} electron volts. The energies in ordinary chemical reactions are of the order of one electron volt. Hence this process offers the possibility of an astounding concentration of energy.

An hypothesis has been advanced that most of the rays received are of a secondary nature, being fragments of bursts which have occurred in the atmosphere. Evidence substantiating this hypothesis comes from the observation that the rate at which bursts of ionization are recorded by ionization chambers or Geiger-Müller counters can be increased by the application of shielding material in reasonable amounts above the apparatus. This has an effect equivalent to concentrating a considerable fraction of the atmosphere near the instrument, indicating that under proper conditions the atmosphere or other matter may become a source of secondary rays. This raises the possibility that the only thing measured by present types of apparatus may be secondary rays, the primary or burst-producing entities being possibly of a different nature. The measured intensity of ionization is found to decrease as the depth below the top of the atmosphere increases. This might result from the fact that the burst-producing entity in traversing the atmosphere loses energy and thereby its ability to produce secondaries is decreased.

At the present time our knowledge of the origin and nature of cosmic rays is limited to relatively meager data concerning the variation of the average ionization with elevation, its value at different locations on the earth's surface and the burst-frequency and burst-magnitude relationships at different elevations. This is in no way due to lack of interest in the problem. The subject awaits the development of superior instruments and probably a fresh method of attack which will bring before us a clearer picture of the primary phenomenon involved as well as more detailed information relating to what actually happens when secondary effects occur.

Thus it can readily be said that the cosmic-ray burst phenomenon remains unexplained, though possible hypotheses exist concerning it. Among these may be the correct one, but for the present our knowledge is insufficient and the data too conflicting to indicate conclusively where the truth lies. So long as the present wide-spread attack on this problem continues it is probable that some day we shall understand better the mechanisms involved, and perhaps benefit thereby.

"MAN AND NATURE"—A CONTEMPORARY VIEW

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FOR a couple of thousand years or more farsighted observers have been impressed with the changes man is making in his environment.[1] A new earth is in process of coming into being, so far as the things man can affect are concerned. What kind of a world will our children have to live in? As a partial help in answering this question let us list some of the things for which man is responsible.

GRAZING

Before man came on the scene the multitudinous grazing and forage-feeding creatures, bisons and other ungulates, rodents and insects, were relatively well balanced with the vegetation. Fluctuations took place, of course, but in the long run grazing pressure and forage resistance were equal. Man's activity in bringing onto the grass country vast numbers of domesticated stock—cattle, horses, sheep and goats—marks the beginning of a new story of the range. The animals were bred in numbers. Feeding methods were improved, water developed, trails, roads and railroads built, and large areas of range made more accessible. In many cases, keen competition and general economic conditions mean stocking on a basis of "all the traffic will bear," and more. Heavy grazing is not confined to the ranges of the western United States, but is in evidence in the East as well. Nor have the effects of over-grazing been confined to North America.

Buttrick[2] has shown that the lack of adequate regulation of grazing has resulted ". . . in the treeless countries surrounding the Mediterranean Sea, the moorlands of Scotland and England, the poverty and desolation of Spain." During historic times grazing is asserted to have been the cause of vastly more forest destruction than commercial lumbering. In England, under a system of stock-grazing in the royal forests, first the game began to disappear and then the timber. Insistent over-grazing in France resulted in such decline of resources that the number of sheep, from 1852 to 1913, decreased over 50 per cent. Human population in mountain regions, in approximately the same period, decreased more than 2,000,000.

In a review of Unwin's "Goat Grazing and Forestry in Cyprus" (Crosby, Lockwood and Son, London, 1928) Buttrick[3] quotes from a high forestry official that from the goat the Cypriot gets ten shillings worth of produce in a year and over a pound's worth of damage. He cites a statement by Sir Joseph Hooker that the goat is one of the chief enemies of mankind. Personal observations on the Navajo Indian Reservation in the southwestern United States makes the writer wonder whether later events will not abundantly confirm Hooker's opinion.

The magnitude of the grazing problem has been pointed out by Barnes.[4]

[1] See Lowdermilk, *Jour. Forestry*, 32 (5): 532, 1934; see also Marsh, "The Earth as Modified by Human Action," pp. xxiv + 629, New York, Scribners, 1898; and Ritchie, "The Influence of Man on Animal Life in Scotland," pp. xvi + 550, University Press, Cambridge, 1920.

[2] *Amer. Forests*, 32: 67–68, 124; 156–159, 190–191; 217–220, 228, 253–256; 293–297, 315, 316, 318–319; 359–362, 377–378, 1926. See also *Jour. Forestry*, 24: 141–152, 1926.

[3] *Jour. Forestry*, 27 (3): 294–296, 1929.

[4] "The Story of the Range," pp. 60, reprinted from Pt. 6, Hearings, Public Lands, U. S. Senate, 69th Congress, 1st session, 1926.

About 586,000,000 acres, it appears, or nearly one third of the total land area of the United States, is arid or semi-arid, valuable only for range and pasturage purposes. Of this land, approximately 186,000,000 acres are public domain. Barnes says ". . . it is so badly overgrazed as to be more of a liability than an asset." The total of land in the United States used for grazing, excluding crop lands pastured part of the year, is about 1,055,000,000 acres, or 55 per cent. of the area of the country.

Recently a series of destructive dust clouds swept over nearly half the United States. According to the Forest Service,[5] these storms originated largely on over-grazed semi-arid lands and former cattle ranges plowed for wheat near the east side of the Rocky Mountains. The dust from the midwestern states blew as far east as the Atlantic Ocean. E. A. Sherman, of the Forest Service, said:

> This is the way deserts start. Excessive grazing, which destroys the protective vegetative cover and permits the ground to be trampled into dust, and the plowing of naturally well-sodded grazing lands for grain crops make it easy for the wind to whip away the dry soil and develop into a destructive dust storm. Wind erosion on the plains is like water erosion in States farther east in its power to destroy rich land in a few years and to transform broad stretches of country into devastated badlands.

It is not a question, as some stockmen mistakenly think, of the country getting drier and the vegetation disappearing. Over-grazing does more than remove valuable forage; indeed, tends to alter many important environmental conditions. Accelerated erosion is promoted. Silting of nearby irrigation works and reservoirs is sure to take place. The soil becomes less favorable for the establishment and maintenance of valuable forage plants. The orderly trend of biotic succession is interrupted and the vegetation is thrown back into various less valuable vegetation stages.[6] A weed problem or a poison-plant problem develops on the over-grazed range. Difficulties with insects, game or rodents are more likely to be encountered than where the normal grass cover is maintained. As Barnes points out, over-grazing, since the earliest records of history, has meant disaster to the live-stock owner as well as the community.

[5] *Science*, May 25, 1934, p. 473.

[6] Sampson, *U. S. Dept. Agric. Bull.* 791, pp. 65, 66, 71, 72, 1919.

Fire

Under original conditions fires in the forest and on the plains occurred at intervals as a result of lightning. Some of the harmful effects of these ancient fires can be recognized even to-day by forest ecologists. The country was big, however, and the inhabitants few. If one section was devastated, the aborigines could move to another.[7]

The coming of civilized man was the signal for a tremendous increase in forest and prairie fires. Some fires were kindled on purpose, others by accident. However they begin, forest fires are now recognized as of high rank among devastating forces liberated by man. The complicated civilization of modern times is so dependent on the wood, grass, soil and water of forest and range areas that an extensive forest fire is likely to be a disaster comparable with a conflagration in a town or city. Indeed, a forest fire may be more serious than a fire in a city. For the city can be rebuilt with relative ease and speed, while soils, forests and watersheds can often be restored only with extreme difficulty, if at all; and such restoration requires a very long time.

Studies in California have conclusively shown that fires interrupt the normal course of succession. One of the

[7] Dr. A. J. Pieters, of the Bureau of Plant Industry, writes (letter of March 13, 1935) that in the long-leaf pine country at McNeill, Mississippi, some cooperative work by the Forest Service, Bureau of Plant Industry, and the Bureau of Animal Industry showed that reasonable use of fire was advantageous to forage production and not harmful to the increase of long-leaf pine.

striking things about the pine region as a whole, as Show and Kotok point out,[8] is the great area of potential timberland now occupied by worthless brush, evidence of the enormous power of repeated fires to eliminate the forest. In another place, these authors[9] state that although in the study of plant environment little weight has been given to fire, even under natural conditions, nevertheless, in the California pine region fire has been a primary force in determining the succession of forest types. The general trend, with repeated fires, is from timber to brush to chaparral to complete destruction of the productive capacity of the site. Already by 1925, in California, nearly one acre of timberland out of every seven had been taken over by brush, as one result of past fires, and it was estimated that the timber which this land could have produced would be enough to run the lumber mills of the state for many years. Fires on a watershed tend to destroy the power of the area to hold the water and to let it down gradually to the valleys below. Denudation through fire promotes rapid runoff, floods, erosion, silting up of irrigation works and lowered water table. Some of these points were all too concretely demonstrated by the results of the terrific downpour of New Year's Day, 1934, above Glendale, Montrose and La Cañada, in the Los Angeles district, California. Fire having previously (in November, 1933) denuded the watershed of vegetation, the flood, laden with detritus, rushed down on the unsuspecting communities involved, carrying death in its wake and depositing tons of earth on the city streets.

According to Forest Service records there were in the United States an average of more than 156,000 forest fires annually in the five-year period 1926–1930, burning over more than 41,000,000 acres of land. Fire was an important contributor to the 81,000,000 acres of unproductive forest land which nature apparently can not reforest without assistance, if at all.[10]

Cutting of Timber

Several years ago Greeley and his associates[11] raised the question whether we ought to *mine* our timber resources, a process sure to lead to their exhaustion, or *crop* them, like other products of the soil. Already at that time, these leaders pointed out, the "mining" of timber in the United States had reduced the original stand from more than 5,200,000,000,000 board feet to approximately 1,600,000,000,000 feet of virgin timber plus 600,000,000,000 feet additional in culled and second-growth stands. Only a remnant of the original eastern forest of 681,000,000 acres—namely, 60.7 million acres—remained, while nearly half of the virgin forests of the West had gone (originally these forests totalled 140.8 million acres; at the time when Greeley and associates wrote, this forest had been cut to 77.4 million acres). Nor had it been found possible to use the cut-over land for agriculture. To-day, in the midst of a depression (1934) the problem is more exigent than ever, although masked by a seeming over-production.

From the ecological view-point the cutting of the timber is but a single incident in a long train of associated events affecting all the plants and animals of the area. In many cases lumbering meant clear cutting, with resultant elimination of forest plants, wildlife and soil. Future productivity of the land was seriously affected. Watershed values were modified. Secondary successions following cutting were always somewhat

[8] *U. S. Dept. Agric. Dept. Circ.* 358, pp. 8–9, 1925.

[9] *U. S. Dept. Agric. Dept. Bull.* 1294, p. 29, 1924.

[10] See Greeley, Clapp, Smith, Zon, Sparhawk, Shepard and Kittredge, Yearbook, U. S. Dept. Agric., 1922, p. 84, 1923.

[11] Yearbook, U. S. Dept. Agric. 1922, pp. 83–89, 1923.

different from the virgin climax forest. Under some conditions wild game was benefited, in others interfered with. Drastic change was the order of the day. We see the results of reckless lumbering in the tax-delinquent-lands problem. The writer has seen potentially productive mountain valleys in the Southwest lumbered off with little regard for the future, their settlers, living in the shadow of poverty and misery, engaged in a hopeless struggle against insuperable economic odds.

Well may we heed the prophetic voice of Marsh:[12]

> . . . the vengeance of nature for the violation of her harmonies, though slow, is sure, and the gradual deterioration of soil and climate, in such exceptional regions, is as certain to result from the destruction of the woods as is any natural effect to follow its cause.

It is of great moment that the present national administration (1935) in the United States is exerting strenuous efforts to stem the tide of deforestation and related wasteful practices and get us back on a basis of conservative use of natural resources based on conservation principles.

Accelerated Erosion

Erosion is an important natural process which has been in operation as long as the earth has existed in its present form. This is the "geologic norm of erosion," as Lowdermilk[13] calls it. Unfortunately, man, in some of his enthusiasm for getting ahead, has overdone his alteration of nature's arrangements, so that the natural erosional process has been disastrously accelerated.

In farm districts, cultivation of the soil, coupled with removal of the natural vegetation cover, often promotes accelerated erosion. In forest areas the removal of trees, usually associated with fires and overgrazing, has the same effect. On stock ranges, heavy grazing by cattle, horses, sheep and goats exercises a similarly far-reaching and often serious influence.

All over the United States and, indeed, throughout the civilized world, the harmful effects of accelerated erosion are being recognized as never before. Kotok[14] pointed out that experiments in California have shown that removal of forest cover by fire increases the surface run-off of water from fifteen to twenty times. Lowdermilk and others have found that forest litter figures importantly as a preventive of abnormal run-off. In the California experiments the eroded material was 2,300 times as great from burned plots as from unburned. Erosion is costing American farmers at least $200,000,000 per year, Kotok asserted. Constructive studies in this field by Bennett,[15] Lowdermilk and others have aroused the public to an earnest desire to do something about it all. Long ago Marsh[16] called attention to the alleged fact that in Upper Provence and Dauphiny, France, the augmented violence of torrents following clearing had swept away or buried in sand and gravel more land than had been reclaimed by clearing.

Burrowing rodents are sometimes responsible for serious erosion results. In every case observed by the writer, however, the original disturbance has been by man.

The consequences of accelerated erosion are well understood in the West, where the silting up of irrigation works, filling of reservoirs, clogging of top soil with accumulating sediment so that the soil "freezes" and will not take water, gullying, lowering of the water table and consequent progressive desiccation of affected areas are all too often noted. It is less realized that erosion has been an important factor in the decline of acre

[12] *Op. cit.*, p. 294.
[13] *Jour. Forestry*, 32 (5): 532, 1934.
[14] *Amer. Forests*, 38 (7): 399–400, 1932.
[15] Sci. Monthly, 27: 97–124, 1928.
[16] *Op. cit.*, p. 243.

yields of wheat in part of the wheat belt, of corn in extensive areas of the Middle West and of cotton in the South.

According to Knight,[17] as a result of a five-inch rain which fell in the Black Belt of Texas in May, 1930, the rich top-soil, from land planted to cotton on an average slope, was washed away at the rate of twenty-three tons per acre. At Spur Station, Texas, Bennett[18] reports (p. 112) that erosion on a 2 per cent. slope amounted to forty tons of soil material per acre with 27 inches of rainfall. In the fall of 1927, he points out, a single rainy period in northeast Kansas took off more than forty tons of soil per acre, the young grain being largely washed out.

The results of overgrazing and deforestation, as related to erosion, may be apparent at points far distant, both in time and space, from the site where the original damage is done. Thus accelerated erosion, resulting from a too thorough cutting of timber or too heavy grazing of live stock, may help to fill and render useless an irrigation reservoir or cause a flood in the lower country hundreds of miles away. Most of the destructive effects of over-grazing on the plant cover are registered during the driest season or the driest year. But the terrific floods so often resulting from a denuded watershed, and associated with an all-too-rapid silting up of the lower portion of the rivers, take place in the wettest season or the wettest year, often by many months or years removed from the particular period when the damage was actually done on the upper reaches of the watershed.

Farming

I do not wish to imply or assert that all man's activities in modifying his environment are harmful. Through farming, closely associated with invention and industrial development, man has distributed useful plants and animals throughout the world and has enormously increased the production of food and clothing. An interesting temporary result, in America at present, is that seemingly overproduction rather than shortage is one of the most pressing farm problems.

As one animal species among others on the earth man is highly successful. One criterion of biological success is population. With something like a billion and a half persons in the world, the population increasing and standards of living tending to advance, man exhibits a toughness and a vitality which places him in a position of unquestioned supremacy. His ability to speed up production of plants and animals is an essential element in his maintenance of this position.

The flowering of man's intellectual, artistic and political life also has been associated with his increasingly effective practice of the art of agriculture. The machine age has been registered in farming operations, as in other fields. Better machinery and more power have meant more rapid modification of the original environment—more sod broken and land plowed, more trees planted or cut down, more cotton, corn or wheat seeded or harvested, more hogs bred and raised, more rapid transportation of farm products.

There is in southern California a huge ranch where the production of hogs has been as nearly mechanized as it is possible to make it. One sees the new-born pigs in one series of pens. In other pens one may follow all ages up to the mature animal. Trains on the one side haul in carloads of garbage from the city for feed, and on the other haul out carloads of hogs to the market. Here is mass production of an important farm product, with a maximum of mechanical assistance and a minimum of man power.

We must continue to farm. But we

[17] Official Record, U. S. Dept. Agric., 11 (27): 153, 1932.

[18] Sci. Monthly, 27: 112, 103, 1928.

shall apparently have to pay increasing attention to the problem of "sustained yields." The soil, the water resources, the native vegetation and animal life must be conserved. The utmost of our ingenuity and technical insight will apparently be required. Agriculture must become less an art, more a science.

Our economic system is in process of being redesigned to place the emphasis on conservation rather than exploitation. The greatest rewards must be given, not to those who exploit our fundamental resources most successfully, but to those who, while maintaining high standards of production, take the best care of the renewable resources with which they deal.

Elimination of Native Plants and Animals

The elimination of native plants and animals takes place largely in three ways: (a) Occupation of the land by man and a resultant crowding out of native species; (b) harvesting of indigenous species for sale or for sport; (c) ridding the occupied area of plants or animals regarded as pests.

(a) The story of the dispossession from its original range of the American bison is well known. Similar disturbances of outstanding game species have taken place in other places. The aurochs of Europe, the beaver in England, the white rhinoceros of Africa, the marsupial fauna of Australia, all have a profoundly different status as a result of occupation of the land by man.

The tendency is for all the larger, more beautiful and more conspicuous creatures, those which for any reason catch the attention of the hunting public, to go first.

Both the primeval forest and the animals in it were regarded by early settlers in eastern North America as serious obstacles to their progress. Our sturdy and self-reliant ancestors resolutely cut down the forests over great areas, and in the process crowded out many of the forest animals.

The consequences of single disturbing acts may be far-reaching. When a plant is removed all the fauna dependent on it goes too—birds, mammals, insects and the lesser forms that dwell on or in its roots, bark or foliage. Similarly with an animal—all its parasites, within and without, are taken away when the animal disappears, along with any obligatory symbionts or commensals it may possess. Good riddance? Perhaps—but the process of disturbance, carried somewhat further, is followed by consequences one would not, perhaps, anticipate or desire.

For example, when a forest is removed, not only the trees, but the entire forest animal and plant population, numbering hundreds or possibly thousands of species, is quite likely to go too. Soil conditions are changed and even the microclimates affected. Removal of a dominant species of plant or animal is not a simple process of subtraction. Determination of what is left depends on a new appraisal of the total situation.

Of course other species tend to flow in to fill the gaps, but the new biotic community is different. It may be characterized by more brush, by more game animals of certain species, by a considerably increased number of insects, by a decidedly augmented rodent population.

The extent to which man's occupation has gone and the degree of disturbance of nature which has resulted are little realized. The changes for which our irrepressible species man is responsible are not confined to closely occupied areas. They extend even to the far-flung forested districts, to the plains, the mountains, the deserts and the waters of the sea. Man's exploitation reaches far beyond the sound of his voice or the touch of his hand at any one time.

(b) As with occupation of the land, so with *harvesting* the crops, especially the

natural products of trees, forage and wildlife, there is a large chance of permanent losses of native plants and animals. Many years ago it was found that native or natural products, such as wild game, are at a disadvantage under a system that puts the chief emphasis on making a great deal of money in a very short time. Under such a system, short-term economic necessity dictates procedure rather than future needs or scientific conservation.

Commercialization has so far as possible been eliminated from wild game. The trend is toward the removal of other fundamental natural resources, as the forests, from the field of unlimited competitive exploitation for private profit. Alert leaders now recognize that some more inclusive formula than immediate personal gain must be invoked and applied if wastage and irretrievable loss of natural resources are to be prevented.

One of the humiliating features of the situation is the thoughtlessness, the carelessness with which man has blithely addressed himself to the exploitation of these great natural sources of wealth. His attitude has put a premium also, not on the wise use of resources for the general welfare, but on monopolization by the most ruthless and acquisitive of mankind for the benefit of a limited number.

(c) Pest control has received a good deal of attention from an early period. In many localities man must still struggle hard for his very existence, against other living things that would kill him or feed upon him if they could. Some of the natives of India are reported to live in fear of the man-eating tigers, which still infest certain portions of that country. Everywhere man must do his best to control or eliminate disease germs. Certain species of insects are responsible for troublesome and costly difficulties. The brown rat and certain other rodents are destructive and dangerous. Of much less importance are the so-called predatory animals in our own country—although their work is often spectacular and of a good deal of importance in certain areas. Within a few days (June, 1934) a certain wolf in Arizona is reported to have killed a number of range cows heavy with calf, and consumed only the embryo!

Seemingly control should be applied with great caution. Premature or mistaken control operations may do much harm. Dr. A. J. Pieters, of the Bureau of Plant Industry (letter March 13, 1935), reports that the fight against alligators in Florida had resulted in a decreased supply of fish. This was entirely contrary to expectation. The alligators were found to prey mostly on turtles, which feed largely on fish eggs.

A similar incident in another field is cited by Stoddard.[19] The marsh hawk is the most numerous of the larger hawks of the Thomasville, Georgia, region. It was occasionally noted killing quail. But examination of approximately 1,100 pellets of the marsh hawk showed but four quail, while one or more cotton rats, a serious enemy of quail, were found in 925 pellets. Instead of being a quail enemy, as might be concluded from a superficial knowledge of the situation, "the marsh hawk is probably the best benefactor the quail has in the area."

There are three things that ought perhaps to be said about animal control. The first is that control is made necessary by man's inevitable disturbances of the natural balance that existed prior to his advent. The second, a corollary of this proposition, is that a great deal of costly control, whether of disease germs, brown rats, insects, rodents or predatory animals, can undoubtedly be eliminated as we are able to reestablish natural equilibria and employ scientific management. The third is that over-drastic control is likely to defeat its own object.

[19] "The Bobwhite Quail," Scribners, New York, p. 209, 1932.

Seemingly we could get along very well without some of the trouble-making micro-organisms that produce our all-too-prevalent diseases. But with the vertebrates, especially, the Biological Survey has come very definitely to the position that, except in the rarest cases, extermination is not desirable—indeed, that the best control is that where the maximum of protection is afforded with the least killing. It is increasingly realized that elimination of all the coyotes, for example, might complicate the rodent situation and make things worse instead of better.

Depletion of Fisheries

While it has been man's experience that in many places the game fishes of the terrestrial streams, rivers and lakes may easily become depleted, the sea, and the fishes of the sea, have often been regarded as symbols of inexhaustibility. Records for the last few years of the cod fisheries of the Atlantic and the halibut and salmon fisheries of the Pacific indicate the error of these notions. Man's over-fishing or fishing at wrong times of the year or in wrong years threatens the integrity even of this generous food resource.

Over-grazing and burning of forests contribute to fish depletion in streams through forests and range lands: over-grazing by promoting turbidity of the water, forest fires by conditioning the addition of chemicals to the water which are poisonous to fish.

Pollution of waters is a major difficulty in industrial areas, as in Illinois and New York, where the problem has received much attention. The liberation in streams and lakes of the chemical wastes from industrial operations, of sawdust, sewage and miscellaneous materials has an exceedingly destructive effect not only on fishes but on fish food as well as on other plants and animals.

Pollution of lakes and bays along the seacoast by sewage and industrial waste products also has a bad effect on a number of aquatic organisms. In some instances oyster beds have been seriously affected by pollution.

Closely related to the depletion of fisheries by pollution are the unfortunate effects on sea birds of the release of oil on the waters by tankers or other vessels. The oil clogs the feathers of many species of these birds, eventually causing their death.

Drainage

Drainage affords an excellent example of the complete removal of an original habitat, with practically all the plants and animals in it.

The late Dr. E. W. Nelson, former chief of the Bureau of Biological Survey, and following him, Paul G. Redington and Dr. J. N. Darling have shown the extent to which our waterfowl are affected for the worse by unwise drainage projects. At the fifty-seventh annual meeting of the American Forestry Association Redington[20] asserted that as a nation we have been dealing with our marshlands much as we have with a great many other natural resources, acting first and considering the consequences later. He pointed out that the census figures for 1930 show that drainage has taken away from our waterfowl, in whole or in part, approximately 77,000,000 acres in the continental United States. While some valuable additions have been made to farm lands, there have been many rank failures. On tens of thousands of acres, asserted Redington, no success in farming has been achieved and many drainage districts are heavily in debt or even defunct.

Every drainage project eliminates certain natural fish, game, recreational and fur or other resources in the hope that others (usually agricultural) will be of greater value. In many instances the

[20] *Amer. Forests*, 38 (7): 400, 412, 1932.

original resources have proved to be more valuable than the newly developed ones.

When drainage of a natural marsh area is proposed, the only business-like procedure is to make a bio-ecological appraisal of resources to be affected and as adequate a comparison as possible of present and anticipated future values, in the light of all available information and of drainage experience in other places.

Irrigation Agriculture

An ideal of man for many years and in many places has been to "make the desert blossom like the rose." Some of the most productive of the world's farm lands, as in the Salt River Valley, Arizona; and in Imperial, Los Angeles and Fresno Counties, California, the valleys of Mesopotamia, the Nile, and numerous others, exemplify some present-day possibilities. In other localities success has been less apparent. Where the supply of water for irrigation has been of fluctuating character or insufficient; where the soil or climate has not been suitable; where the right crops were not used; where pests from nearby wild lands have been too much in evidence and have not been economically controllable; or where distance to markets was too great, irrigation enterprises have not paid.

Irrigation projects may be compared with drainage. In both cases the original habitat is almost completely altered and a new biotic community introduced. The resulting situation is completely artificial. Both irrigation and drainage are extremely expensive. Usually the sites are at some distance from markets. In both cases the land must be suitable for growing crops. If there is too much alkali in the soil in either case, failure will result. The risks are great. Just as the waterfowl, fishes and some of the other aquatic forms represent a real resource that is lost in drainage enterprises, so the forage plants of arid localities are valuable for grazing, and the wild game for recreational use. The real value they represent is likely to disappear when the land is "reclaimed" and brought under an irrigation project.

According to our present economic arrangements local over-production is obvious, and extreme caution should be exercised in either draining or reclaiming wild lands any further. A sharp alteration in national policy seems to be called for.

Ordinarily the natural production of an area, as forage and wild game on a grazing range, is reliable and may be counted on. But the maintenance of irrigation agriculture offers numerous difficulties. Unless there is a way to get rid of waste water, the water level in the soil may rise unduly, evaporation take place, chemicals accumulate, the soil become waterlogged and often alkaline in character. Fine-grained soils sometimes become sealed up by sediment in the irrigation water so that in the end the water stands on top of the ground and will not sink in. There is a question whether any great irrigated land area in the world except that lying under the Nile (which has the advantage of alternate flooding and drainage) has been kept in continuous production indefinitely.

As Thornber[21] says:

> . . . the natural tendency of all our arid lands is to revert to their natural desert condition, and nothing but the most intelligent efforts of man can prevent this.
>
> In the history of mankind this fight against the slow forces of nature in arid countries has been a losing one, and, except in the Valley of the Nile, where irrigation has been carried on under peculiar conditions, we have yet to find a single example of a permanent irrigation agriculture.

Neither drainage nor irrigation should be planned on lands which are already of

[21] Univ. Ariz., Ag. Exp. Sta., *Tech. Bull.* No. 6, foreword, January 15, 1926.

value for recreation, forestry, grazing, or wildlife production unless substantially increased returns, as shown by comprehensive scientific and economic studies, are reasonably well assured.

Vitiation of Air

While the extent to which man can affect the total atmosphere is limited, nevertheless some results of industrial operations may be far-reaching. The fumes from smelters, which contain sulfur dioxide and perhaps other poisons detrimental to plants, have often ruined nearby vegetation, especially browse and trees. Grass seems to be much less affected than certain other species. The pall of smoke and other cloudy substances that hangs over most of our industrial districts must exercise some effect on the plants and animals that have the misfortune to be subject to its influence, though the writer has seen no convincing studies of the subject.

Stocking and Restocking Enterprises

By "stocking" is meant the carrying of animals or plants from their natural habitat to some other; by "restocking," the reintroduction of a species where it once occurred naturally.

A moment's consideration will show that reactions of unusual importance have taken place as a result of stocking enterprises. I need only recall the case of the European rabbit in Australia. Other well-known cases are afforded by the introduction of the American gray squirrel into England, the muskrat on the continent of Europe and the English sparrow and the European starling into the United States. The introduction of pigs on Mauritius and Rodriguez Islands is said[22] to have brought about the total extirpation of the dodo and solitaire, respectively. Goats were introduced on St. Helena in 1513. In 1810 it was realized that this "precious oasis of tropical plant life" in the midst of the Atlantic Ocean had become a barren and rocky waste. The forests were gone, leaving no successors.

In some of these instances, particularly, the original biotic community has been shaken, disturbed, well-nigh destroyed. Previous to the introduction one could scarcely have anticipated its far-reaching consequences.

It is true, of course, that most of our agriculture is a process of "stocking." Excellent producers of food or materials for shelter are discovered among the plants and animals of the world. Farming domesticates the animals, cultivates the plants and distributes them both wherever they will grow. The small grains, corn, alfalfa, the domestic fowl, the dairy and range cow, the horse and the hog are cases in point. This process of scattering valuable products has contributed mightily to the ascendancy of man, as already pointed out. There *are* some advantages to civilization.

But along with the beneficial phases of introductions have gone some interesting cases of involuntary importation, as of plant pests and parasites—white pine blister rust and chestnut blight; household pests—the brown rat and the house mouse; diseases of man and other animals — bubonic plague, smallpox; harmful insects—as the corn-borer, Mediterranean fruit-fly and Japanese beetle in America, and the Colorado potato beetle in Europe.

It is obviously of vital moment to the citizens of the United States that introductions shall be of the right kind. On one side the Government maintains a small group of agricultural explorers who comb the earth for improved varieties of plants. On the other the Government finds it necessary to set up what is virtually a "plant and animal immigra-

[22] Ritchie, "The Influence of Man on Animal Life in Scotland," Univ. Press, Cambridge, 1920; reviewed by Detwiler, *Jour. Forestry*, 28 (1): 80–82, 1930.

tion service" along our borders, where the U. S. Bureau of Entomology and Plant Quarantine exercises rigorous surveillance over all incoming plants. The importation of animals likewise is carefully regulated under the Lacey Act, administered by the U. S. Bureau of Biological Survey.

Problems of stocking and restocking come strongly to the fore in fish and game administration. The former tendency of sportsmen and their representatives almost everywhere was to bring in game birds or mammals from somewhere else. At present progressive sportsmen are trying to get the states and the Federal Government to concentrate all possible resources on the maintenance and increase of valuable native species. It is true that some successes have been recorded in the introduction of game—especially of the ringnecked, or Chinese, pheasant—in England and in many states of the United States. Probably the overwhelming majority of game introduction projects, however, have resulted in failure and waste of the sportsman's money.[23]

An essential preliminary to any proposal for game importation or any sort of "stocking" should be a detailed ecological study of the species at home, with special reference to its habits and habitat and the conditions it will encounter in its new location.

While the burden of evidence is against the importation of foreign game, the bringing back of species of game formerly occurring in an area is another story. Even in these cases it is essential for success that certain precautionary studies should be made prior to the event. The habitat ought to offer reasonable chance of survival—if the original forest is lacking there is little excuse for restocking forest game. If the grass and food plants have been grazed off there is no hope for success in bringing back grass-inhabiting species. The conditions as regards food, shelter and maintenance must be suitable. If agriculture has grown up about a mountain range so that reintroduction of elk, originally present, would be attended by difficulties to the residents, restocking should not even be attempted. It goes without saying that animals used for stocking or restocking purposes should be free from disease. Other important points are to liberate a sufficiently large number of individuals to give some hope of their survival, and to give them legal protection at least until they become established.

Fishes of various kinds can be handled much more economically and practically than, for example, game birds. Following the discovery of the possibility of the hatchery method of propagating game fishes, stocking and restocking suitable waters has become routine practice wherever conservation departments operate.

The chief weakness in the whole problem of the transfer of plant and animal species is an imperfect knowledge of their ecology, and, in some cases, failure to use available data. More high-quality information and an increased reliance on specialists would go a long way toward saving funds and really conserving and increasing our resources. If a tithe of the money that has been spent on fruitless restocking enterprises had been used for scientific research and its applications, it is safe to say that we would possess substantially larger numbers of game animals than we do at present.

Preservation of Game

A few years back one would scarcely have anticipated that over-protection of game would become a difficult and troublesome problem anywhere in America. But such is now frequently the case.

A notable instance is afforded by the Kaibab National Forest, in northern

[23] Those interested should consult the long list of attempted game introductions given by Phillips, *Tech. Bull.* 62, U. S. Dept. Agric. pp. 1–63, April, 1928.

Arizona, already widely discussed in the literature of conservation. As shown by this striking episode, game surpluses may exercise an exceedingly detrimental effect on the vegetation of their habitat, which of course means ultimate serious consequences to all animals and to the soil. Clepper[24] asserts that deer in Pennsylvania have increased to 800,000 head in 40 years, which is three times the optimum carrying capacity of the forests. In many localities they have destroyed the undergrowth, including mountain laurel and rhododendron, effectively prevented natural forest reproduction and even destroyed extensive plantations of various hardwood and conifer species. Over-population has also led to decrease in deer size and vigor, and has also, by destroying their food and cover, greatly reduced the population of small game. Remedies suggested include the reduction of the herd, the shooting of does and the promotion of better distribution of deer through the forested parts of the state.

Ultra-preservation of game, as on the Kaibab, changes the habitat and may affect all the plants and all the other animals. The potential seriousness of carrying a good thing too far has been little realized in the past, but is now receiving consideration in many places. Neither ultra-protection on the one side, nor extermination on the other, is desirable. Scientific wildlife management, considering the needs of the entire biotic community in its environment, is increasingly realized as the proper objective. Any management worthy of the name must include the possibility of reduction as well as increase in the resource under consideration.

The Balance of Nature

Many scientists have apparently become somewhat skeptical regarding the existence of any balance of nature. In one sense there never was such a balance. Nature is not static and never was. It is wholly normal to expect wide fluctuations in numbers of plants and animals, considerable swings of climate, back and forth, and ample variation in all characteristics of individual, species, community and environment.

But in another and a very real sense the balance of nature does exist and is one of the important features of organism and environment. As has been previously pointed out, just as in physics and chemistry, for every action there is an opposite and equal reaction, so in the living world. When more is added here, something is subtracted there. The balance of nature is a fluctuating relationship between the organisms of the biotic community among themselves and between the biotic community and its environment.

It is true that all the modifications of his environment by man that have just been considered tend to change the natural balance. The old balance, existing before man came on the scene, is gone forever. A new balance, however, has been struck. More accurately, new balances are being struck in each succeeding interval of time, since conditions are never twice the same.

It is inevitable that man should so far as possible order nature to suit himself. Every other living creature tries to do the same. There is no reason why any former condition of things should be perpetuated. Indeed, with the increase in numbers and activities of mankind the old balance of the caveman days or prehuman days is as undesirable as it would be impossible. Even if man were not a member of the world fauna, the balance would continuously fluctuate.

But man does have some obvious responsibilities in reference to the natural balance. His modifications of nature

[24] Pa. Dept. Forests and Waters, *Bull.* 50: 5–45, 1931.

should be so carried forward as not to make the new balance harmful to him. That is why the people are turning increasingly to the better regulation and control of their common natural resources, whether they be minerals, forests, wildlife, forage, soil or water. Pertinent to this discussion are the following gems from Trader Horn's philosophy: "Aye, the balance of nature—leave it alone and it'll function to perfection." "And believe me, when man has destroyed nature then it's his turn to go."

In order to be constructive, it is often necessary to be critical. The whole weight of commercial operations and the profit system is inevitably on the side of short-period exploitation of natural resources. While the writer has no intention of leaving the impression that proper use of the things around us is harmful, he feels that increased attention to some of the present and future consequences of our actions is absolutely essential.

Through unremitting research, concentrated intelligence, courage and unselfish cooperation, man must attain a place where he is not destroyer, but master-manager-conserver of natural resources. This objective he must win to insure his own survival. He must avoid over-specialization, while at the same time he learns more about each department of nature. He must exalt the view of nature as a unit and make his management programs conform to the needs of this larger and more adequate outlook.

Somebody once suggested a moratorium on research, but such a moratorium would mean retreat to a régime of scarcity and a lower standard of living. Enlightened research, in the social and economic fields as well as in natural science, and its applications are the most important activities in which man can engage. Our trouble is not too much knowledge, but too little. There are no surpluses of intelligence, courage and unselfishness.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

THE STORY OF ORE DEPOSITS

By Dr. EDSON S. BASTIN

PROFESSOR OF ECONOMIC GEOLOGY AND CHAIRMAN OF THE DEPARTMENT OF GEOLOGY, UNIVERSITY OF CHICAGO

You of the radio audience are listening to this broadcast through sets built of many different kinds of metals. You know perhaps that these have come to your home from mines in the remote corners of the globe—from China, from the Malay States, from South Africa and perhaps other distant places. To-day I would like to tell you something of the ways by which nature created those treasure houses of the metals that we call our ore deposits in which our mines are located.

The winning of nature's secrets requires acuteness and patience. This is true even of those processes which can be watched and studied from their beginning to their end, but it is especially true of many of the processes with which the geologist is concerned. Most geologic processes proceed at so stately and leisurely a pace that the span of man's life is far too short to compass them in their entirety and he is forced to fit together isolated observations like the fragments of a jig-saw puzzle to form a complete picture. Experiments in the laboratory, imitating the natural processes in miniature, speeding them up and giving them continuity, may, however, furnish a useful check on the conclusions from such scattered observations out-of-doors.

In the solving of other problems the geologist is under even more serious handicaps. Many of earth's processes are not visible at all to human eyes but take place deep within the earth far beyond the reach of the deepest mine or even of the deepest drill holes which probe to depths of more than 12,000 feet. There can be no hope of ever seeing these processes in action, but the slow wearing down of the earth's surface by the rain and the rivers finally reveals to us the effects that they have produced, as the paring of an apple may make visible a hidden blemish. In such cases the geologist, like a detective who did not see the crime he is set to solve, must rely wholly on circumstantial evidence and deductive reasoning.

The processes by which most of the ores of the metals have been formed are in this difficult class, and so it has happened that, in spite of its practical importance, ore formation has been one of the last of the great geologic processes to be understood. Only in the past generation has there come to be much agreement in opinion concerning it, and even now we might feel doubtful of its solution had not almost all other possible explanations been tried and discarded because they failed to fit the facts.

The explanation that has finally emerged through centuries of trial and discarding of theories, dating back to the Middle Ages, seems at first acquaintance not especially plausible, but we must recall that nature often creates strange bed-fellows. Our metal mines do not usually associate themselves in our thoughts with volcanoes. Yet to-day the evidence is clear that most ore deposits are products of ancient volcanic

action or, as the geologist calls it, volcanism. But why, you may ask, has such a partnership between ore formation and volcanism been so long a mystery, since we have learned to know and understand so well the spectacular processes displayed at Vesuvius, at Etna and at hundreds of other volcanoes scattered widely over the earth? The answer is that the formation of ores is not associated with those phases of volcanism that appear at the earth's surface in volcanoes and their attendant phenomena. Had such been the case we should long ago have understood their origin. Rather, the ores are related to those kinds of volcanism that only occur deep below the surface and find expression in the slow cooling and solidification of deeply buried masses of molten rock material. Many lines of evidence have led to this conclusion of the partnership between ore deposition and deep-seated volcanism.

The fact is that by and large, and making one allowance for certain ores that clearly have a different origin, regions of ore deposition are also regions of volcanism. If we compare two maps of North America—one showing the distribution of igneous rocks and the other the distribution of ore deposits—the maps are nearly identical. In the United States, the West from the Rocky Mountains to the Pacific is our great mining region, and it is there also that volcanism —ancient and modern—occurred on the greatest scale.

Again, some ore deposits are observed to pass by the most gradual transition into common and familiar rocks that we well know, solidified from a molten state. If one was once molten, the other must also have been. The chromite deposits of far-off Rhodesia, from which come the glint and glitter of the chrome plating on your car, are of this class of deposits.

But not many ores formed within the very heart or center of volcanism as did these. Most of them lie not within the volcanic rock itself but close to it in the bordering rocks—and of this sort are nearly all our mineral veins. Obviously, these ores are not themselves metal-rich volcanic rocks as were the chrome ores. They have been deposited by metal-bearing solutions exuded from the volcanic rocks into the bordering rocks where they deposited their load of metals.

One of the most convincing evidences that ore-forming solutions have been given off from volcanic sources is furnished by the Braden mine in Chile. There above timber-line in the high Andes is a colony of American mining engineers who have developed one of the largest and in some respects the most unique copper mine in the world. There nature, using the rivers as her carving tools, has sculptured the earth's surface with bold strokes, cutting on the bias a section through an ancient volcanic vent and exposing it like a gigantic open book for the geologist to read. The ancient volcano is the Braden copper mine, and when the geologic story is unraveled it is found that at the site of the old volcanic vent there came repeated alternations of volcanic activity and ore deposition: first rising mineralizing solutions, then volcanic eruption, then rising solutions that formed copper deposits, then renewed volcanic activity and finally more copper-depositing solutions. All were confined to the old volcano or its immediate vicinity, and the conclusion is difficult to escape that all came from the same volcanic source. Thus was developed one of the strangest copper mines of the world—a hollow cylinder of copper ore occupying the periphery of a vent wracked and shattered by volcanic explosions. It is possible for the miner to travel underground for miles in these mine workings, making the complete circuit of the old volcanic vent and returning to the point from which he started.

It is not needful, however, to travel to

Chile to find ore deposits closely confined within an old volcanic vent. One of the famous gold camps of our own West is Cripple Creek in the Rockies of Colorado, easily reached by a scenic highway from Manitou. There an old volcanic vent two miles across has been sliced nearly at right angles by erosion. The gold-bearing veins that made this camp famous are all within the filling of the old volcanic throat or in the immediately adjacent walls. Deposition of rich gold ores followed close upon the heels of volcanic action and both rose from the same deep source.

In a very few mines the processes that formed the ores still seem to persist in a feeble and impotent way. At the great Comstock Lode at Virginia City, Nevada, whose palmy days were so vividly pictured by Mark Twain in "Roughing It," the waters in the deeper workings 3,500 feet below the surface were hot enough to cook eggs and scald flesh and the miners often worked in 15-minute shifts with a hose of cold water playing on them. In these waters the chemist finds small dissolved amounts of the metals. They seem to be the dilute successors of the hotter and more concentrated waters that deposited the ores.

I have tried to give a picture of the processes by which the majority of ore deposits have been formed deep within the earth. When, however, erosion has stripped off their covering and exposed them at the surface they are opened to the chemical attack of the gases of the air, to the dissolving action of percolating rainwater and to the wash of streams—in short, to all those processes which the geologist calls "graduation," by which some parts of the earth's surface are worn down and others graded up. Thus is begun a second chapter in the history of many deposits of the metals. If the worthless components of an ore deposit are dissolved by the surface waters and carried away, the part that remains behind, being no longer diluted by them, becomes proportionately richer in valuable metals. This was the secret of the extraordinary richness near the surface of many of the gold veins discovered by the prospectors of the golden 50's in Colorado and California—a richness never duplicated at greater depths. Some of the gold from the rich outcrops of the veins is likely, however, to be washed down the hillsides and accumulate in the gravels of the neighboring stream beds to form the placer deposits that yielded their treasure so abundantly to the forty-niners through simple methods of surface mining.

Not infrequently the effect of the air and surface waters is quite the reverse of that which has just been cited, for the valuable components of a deposit of the metals may be the ones dissolved, leaving the worthless material behind. The valuable metals thus dissolved may be carried away and scattered beyond the possibility of recovery, but fortunately in many cases they are reprecipitated in deposits rich enough to be worked. At Butte, Montana, the greatest copper camp of the United States, copper dissolved from the outcroppings of the veins was reprecipitated deeper down within the veins making them richer than they were originally.

Under other circumstances the metals dissolved from ores or even from ordinary rocks of the land surface may be carried to the ocean, there to be precipitated as metal-bearing sediments. In such a manner were formed the large iron ore deposits of Birmingham, the great steel-making center of the South. Thus in nature's laboratories have gone on the natural processes of concentration of ores that have made the metals available for our human needs.

ASTRONOMY AS A HOBBY

By Dr. OLIVER JUSTIN LEE

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REAL avocations or hobbies usually *elect themselves* into the conscious life of an individual. They often come into a person's life in much the same way that an unexpected comet comes into visibility in the sky, as a faint nebulous idea or notion oozing into consciousness like so many other peripheral mental products that pass in and out our minds. Then the idea grows into a definite program or interest. Cultivating a hobby is a real educational activity.

An ideal hobby ordinarily has no connection with a person's vocational or professional work. You are all familiar with specific cases. The following are typical examples of hobbies: Dr. Whitney, director of all the vast research operations of the General Electric Company, raises and studies turtles. Mr. Haaland, a farmer and orchardist in Door County, Wisconsin, is an authority on the ancient Norse explorations and rune writings in the North Central States. Dr. Harlow Shapley, director of the important Harvard College Observatory, finds time to study and write about the lowly but interesting ants. Dr. Graham Laing, professor of economics at the California Institute of Technology, makes with his own hands all sorts of small, serviceable tables in the modern style and gives them to his friends. President Roosevelt and King George of England are both enthusiastic collectors of stamps. Robert E. Millard, flute soloist with the Symphony Orchestra in Portland, Oregon, has built himself a small, but very attractive observatory, and owns several small telescopes with which he is making observations of variable stars and of occultations of stars by the moon. These observations are valuable. The list is almost infinite in length and in variety.

Hobbies are often adopted quite deliberately and consciously. This choice is usually accomplished with much less strain than is present in the choice of a vocation or a profession, which has so many complicating circumstances tied to it—native ability, financial return, social status, opportunity in a competitive world and many other aspects of life have to be allowed for. And unfortunately many people are not happy in their life work. Therein lies a tremendous difference. Every one who has a hobby is happy with it, loves it.

Now frankly, wouldn't the whole world be a different world and more interesting and satisfactory if all the activities in it were regarded as hobbies and every one were permitted to do his part with the enthusiasm and the joy which men have always found in pursuit of a hobby. And we should not need to worry that any of the work of the world would be left undone. With machines being developed for doing almost all the drudgery and most of the really disagreeable tasks connected with living, I venture to say that some one could always be found who would really enjoy doing any one of those jobs which remain to be done in person. The one essential quality common to all hobbies is that they take a person's mind away from his usual work. Just how far away depends upon the mind and personality of the person in question. The examples I gave at the beginning, Dr. Whitney and his turtles, Mr. Haaland and his runes, and so on, illustrate this point.

The history of astronomy through the ages shows that this old science has attracted to it the utter devotion of a great many amateurs, who have contributed immeasurably to its progress, besides af-

fording these men the greatest satisfaction in the cultivation of this avocation or hobby.

To mention only a few: The great Sir Isaac Newton was for the last thirty-one years of his life, 1696 to 1727, the director of the British mint, so that his scientific activities during this period were, in a sense, those of an amateur. In 1857 the Gold Medal of the Royal Astronomical Society of London was awarded to a middle-aged druggist, Schwabe at Dessau, Germany, for his thirty years of observations of sun-spots, and for his discovery of the eleven-year cycle in sun-spot activity—a most important discovery. Our own great Sherburne Wesley Burnham, for more than a generation the leading observer of double stars in the world, was successively a court reporter, clerk of the United States Circuit Court at Chicago and for five years receiver for the Chicago and Northern Pacific Railroad. His astronomical work during these years brought him international recognition.

Astronomers often hear the question "How do you get started in the study of the heavens? The objects in it seem so unreachable." The answer is simple. "Start with elementary phases of the subject. And remember, that most of the elementary considerations are also fundamental."

To put it concretely, you first need interest in or, if you please, curiosity about the great universe. Then you need more interest and a star chart. By the time you have located the North Star or the Great Dipper in the sky and have identified it on the star map your interest will increase spontaneously and in a few evenings you will be able to identify and name the brightest stars in the sky and most of the scattered groups of stars which we call constellations. By this time you will have or will want some up-to-date text-book on astronomy. And remember this—you do not need to know any mathematics beyond common arithmetic to enjoy astronomy and in many branches of this science you may even do important work without using or needing the higher branches of mathematics.

At this point you will want to look through a telescope at some of the fascinating objects in the sky, the moon, planets, double stars, star clusters and nebulae. Most colleges and universities have telescopes which may be used. Then there are many enthusiastic amateurs, all over the country, who have made their own telescopes, which they are always pleased to demonstrate.

After having had the experience of observing with a telescope you are capable of doing any one of a number of things. For example, you may buy a small telescope or you may set out to make your own telescope. If you are mechanically handy, you can, in the course of a few months, make yourself a reflecting telescope of considerable size, at a really very small outlay of money. May I interject here the statement that if you will send a request to Dearborn Observatory, Northwestern University, you will get, without charge, a list of books and other aids which will start you on your way to make astronomy your hobby.

I think of an avocation or hobby as involving constructive activity. For example, just reading about Navajo blankets does not seem to me to be a hobby, while collecting Navajo blankets or writing the story of how and why they are designed as they are, does. Similarly, just reading astronomy is hardly an avocation, but if in addition you should set out to construct a fine star map or a celestial globe with colored chips of glass for stars, or to make a telescope yourself, or settle down to a program of observing variable stars, mapping the paths of meteors or observing the changes on the face of the giant planet Jupiter, then I should say you are making a real hobby of astronomy.

It is probably safe to say that several hundred men in this country are making

telescopes for themselves right now. A considerable number of these amateurs are making or will be making valuable observations, which are being published every month with full credit given to each observer. In the months of July and August of last year alone, 6,727 observations of 402 variable stars were made by 88 amateur observers scattered all over the United States and published in the October number of the journal, *Popular Astronomy*. In many of the leading countries there are Associations of Variable Star Observers whose members have gone about it so seriously and enthusiastically, and to such good effect, that they have practically taken over the whole field of observing the brighter variable stars. Nothing could please the professional astronomer more, for it has released his time for other work.

There are many portals by which men enter the fascinating house of astronomy. Those who try to come in through the reading of such authors as Eddington and Jeans find themselves at once in a long series of reception rooms, the first of which we may call Higher Mathematics, the second room, Classical and Modern Physical Theory. The third room, Philosophy, as done in the style moderne, is colorful but bewildering. As a matter of fact the partition between the two chambers, Modern Physics and Philosophy, has been somewhat noisily kicked down in the last few years. Much of the debris still lies about in both rooms, and the guest who tries to enter the house of astronomy by this entrance quickly loses his way and is quite likely to forget that the glorious panoply of stars, planets and nebulae are still shining, and inviting admiration and study. The haughty guards stationed throughout this entrance are not very friendly or helpful to the beginner.

There is another entrance, the most beautiful and dignified of all, the door of celestial mechanics. Here exists the finest order, the most elegant furniture, the sweetest peace. But the price of admission is mathematical power, and few men have that coin ready at hand. I would not, however, discourage you forever. There are several smaller entrances to the house of astronomy. We may call them cottage doors or garden gates. They lead almost directly into the charming center of the house, and there are no guards to prevent entrance. On the contrary, helpful guides are always at hand when they are wanted.

We may call one of these gates the Chart and Book. You are admitted at once to contemplation of the serene beauty of the heavens. After lingering a while in the outer spacious garden, you will notice another stronger gate, the gate of the telescope. To enter here, you must have a telescope. Having oriented yourself in this part of the house you will find a number of charming gates and stiles and walks leading to rooms or terraces which we may call the terrace of variable stars, the pergola of double stars, the garden of colors of stars, the tea-room of planetary study and the workshop of spectroscopy.

Sooner or later you will find the particular spot in this great house where you can always be happy with interesting and charming companions. There is not the slightest doubt that the world is coming into a high tide of leisure for every man. Our industrial and social economy must be reshaped and adjusted to that idea. Many of us will simply sit and twirl our thumbs in unhappy idleness. Most of us will adopt or develop avocations, non-professional and non-vocational interests of some kind.

May I suggest that you enter the stately house of astronomy by whichever portal or door you prefer. Then express yourself in some activity. Use figures, diagrams, models, telescopes, verse or prose, but avoid barren speculation, until your hair has grown gray and your spirit mellow in the contemplation and study of the marvels of the heavens.

THE MEANING OF MATHEMATICS

By Dr. E. R. HEDRICK

PROFESSOR OF MATHEMATICS, UNIVERSITY OF CALIFORNIA AT LOS ANGELES

I SHALL try in the short time at my disposal, notwithstanding real difficulties, to tell you something of the meaning of mathematics. Mathematics arose early in human history; in fact, before there was written history. The necessity of counting and of simple arithmetic certainly existed in every primitive race. Its first form consisted in counting on the fingers and sometimes on the toes, as witness our own systems of counting by tens and by twenties.

Before any advance in civilization was possible, even more definite and conscious mathematical skill was necessary. Thus it is related that the ancient Egyptians were compelled to create some rules for land measurement on account of the shifting of boundaries in floods of the Nile River. Guesswork gave way gradually to definite established rules for measurement, and these in turn to very well-thought-out rules for such areas as those of triangles, quadrilaterals and circles. Such rules are reported, for example, in the famous and very ancient Ahmes papyrus. Before the pyramids could be built, quite accurate knowledge of geometric quantities and of simple surveying was necessary. Whenever such rules for areas, volumes and surveying are expressed in general terms, then algebra is born. For algebra consists fundamentally in general rules about quantities that are true in all cases, as opposed to the special instances of arithmetic.

Contrary to the too-common misconception of algebra, it is not necessary to use letters to represent quantities. It is the generality of the statements, rather than the manner of expressing them, that constitutes algebra. Thus the statement that the area of any triangle can be found by multiplying half its base by its height is an algebraic statement. The statement that a recipe for making a cake can be used to make a larger cake by multiplying each ingredient by the same number, and intelligent thought as to how this is limited by the dimensions of the oven, is certainly algebra, for it is quite general. Even such thinking does not occur to untrained minds.

From such simpler quantities, the world has advanced, as civilization has advanced, to more and more complex quantities. From the mere areas of ancient Egypt, we have developed intricate and extensive geometric principles and algebraic rules, until such complex quantities as the amount of earth to be excavated in the Panama Canal, the precise weight of a great bridge or a great ship, can be stated before the work starts.

From the humble household uses of ordinary life, we have developed mathematics until we can carry on such complicated operations as life-insurance, the amortization of bonds and mortgages, the understanding and control of nature and natural forces in the sciences that deal with measured quantities and in engineering.

More than all else, mathematics is (and of a right ought to be) a study of quantities and of the relations between quantities. Who is so bold that he will say that quantities (numbers, geometric quantities, business quantities, quantities in science and in engineering) are not fundamental to our civilization, to the lives of all of us? In a word, then, this is the meaning of mathematics: to know of quantities with which the world deals and to know the relations that arise in any of our problems. Thus house-plans involve geometric quantities of size and shape and form, be the house little or be it a great steel-framed office building.

These geometric quantities are connected with quantities of lumber, of cement, of nails and brick and mortar, with quantities of labor and wages; these again are connected with quantities of money and rates of interest, with discounts and with amortization of loans and mortgages. To face such questions, big or little, with understanding, each man should know, each woman, too, who deals with life at first hand, what are the relations between such quantities and how to deal with them.

Such situations, and thousands of other situations large and small, confront society and the individual on every hand, on every day of every year. If these and like things are not taught, it is the fault of the teachers, not of the subject; it is the fault of the educators, not of the fundamental basic parts of real education. In the words of Sir John Perry, "mathematics began because it was useful, survived because it was useful, and will continue because of its usefulness."

Despite this, some say that we may leave all such matters to the "experts": they—the "experts"—will do our problems for us. There are indeed experts in all kinds of quantities: experts in building, experts in business, in banking, experts in the lending of money on mortgages and on instalment buying, experts in home-loan societies and corporations, experts in insurance, experts on pensions, experts on taxation and on the evasion of taxation. I will not decry them as a class. Such wholesale denunciation of business men and bankers has been all too common of late, and I will not be party to it. The greater number, by far, are honest, upright, well-meaning, public-spirited. But, just as in the law there are shysters, just as in the field of medicine there are quacks, so also in the field of business and finance, in insurance, in pensions, in bonds, there are those unworthy of the great businesses which they disgrace, unworthy of protection by the honest business and professional men, as are shyster lawyers and quack doctors unworthy in their groups. It is all too evident that many such, unprincipled, ruthless, greedy, have preyed upon the very ignorance of mathematics (that is, of quantities and of relations between quantities), preyed upon the men (and the women, too) who have been told, perhaps, that they need no mathematics, since the experts will do it for them. Shall I repeat that some among the "experts" have "done" the people, rather than their problems?

What subject so touches life, the lives of all of us? The English language, perhaps: for it I ask your support as a basic fundamental of true education, quite as much as for mathematics. Besides this, what other? History? Law? Economics? How many millions are now struggling—many hopelessly, bitterly—with payments on mortgages and on instalment purchases, made at cleverly concealed rates of interest? How many of these hard-pressed millions of people even know now the actual rate of interest that they are paying? Have you such a problem yourself? Do you know what rate of interest you yourself pay? Do you know that rates as high as 30, even 40 per cent. have been charged by the more unscrupulous? If a radio whose cash-sale value is sixty dollars is sold for five dollars down and five dollars a month for each of twelve months thereafter (a total of $65.00), can you find the actual rate of interest paid? Is it within reason?

A private corporation, representing itself as a sort of agent for the National Housing Act, has recently circulated pamphlets that give the impression that it will lend money at 5 per cent. In fact, the corporation is not an agent of the government, and the actual rates of interest charged in examples stated in the pamphlet are nearly 12 per cent.

By comparison, would the debt-ridden millions have profited more by study of the battles of Napoleon, or even those of Pershing, rather than by a study of the

relations of ordinary interest on money? By a study even of the law of supply and demand, important as that is to us? By a knowledge of the manner of election of our judges or of the powers of federal juries? I mention here no little topics for your comparison; yet which of them can be compared in its direct effect on the lives of people with the mysterious ways of interest on money?

Interest, yes, and many another subject of wide and vital import—insurance, bond-payments, pensions, great buildings and small houses, payments on staggering international debts and your own instalment payments on that automobile of yours; these are based, all of them, on simple principles of mathematics that are taught in every high school, and they could be made clear to all if teaching were less formalized.

Modern science, the radio, electric power, gas-engines, automobiles, airplanes, all railroads, all great buildings, all great bridges, all questions of science that deal with measured quantities, owe their very existence in their modern forms to mathematics as to no other element in our education or in our progress in learning. No informed person will deny the entire truth of this assertion.

Notwithstanding this, there are some minor educational leaders, false to be sure, but often powerful, who say that mathematics has no relation to modern life: Is this then credible? Rather they who say it show only their own misconception of mathematics, or of life, or both. Shall the generation of boys and girls now in our schools know even less about the quantities with which the world works? Shall they—the coming generation—be even more at the mercy of the predatory fringe that disgraces business and finance? Has not our own generation learned sufficiently the folly of ignorance about the many quantities with which it has of necessity dealt, too easily misled by unscrupulous "experts"? Is not the present plight of the whole of society due to light-hearted ignorance of the quantities, sometimes vast beyond easy comprehension, as in the case of international loans, sometimes petty in single instances, as in the deceptive forms of cans used for canned goods? For example, does the public know even now that the orgy of instalment-buying in the late twenties amounted in fact to an inflation? Does it know that this is one of the direct causes of the depression?

Tell only those who have no life that these things are not part of life! Tell only those who are idle that our business is not affected! Tell only those who do not care that society and the individual are not concerned! Tell only those who wish to perpetuate fraud and extortionate usuries that these things need not be taught!

I stand, despite attacks by uninformed minor educators, for defense of the basic elements of all true education, than which none enter more directly into all phases of the national existence and of the daily lives of every one than do the English language and the sort of mathematics that I have expounded—the only sort that has any right to be called mathematics—the intelligent dealing with the quantities with which the world works. I desire that schools reform, not by banishing study about quantities because it has been poorly done, but rather by improving the teaching regarding these things, and by avoiding misconceptions, such as that which I mentioned concerning the nature of algebra. I demand for our children better—rather than worse—preparation than we have had to face a world in which quantities arise on every hand, in every walk of life, to every active man, to every active woman. Thus, and by no other means, may our sons and daughters build a greater and a safer society in this world of quantitative things!

DR. SIMON FLEXNER

THE PROGRESS OF SCIENCE

DR. FLEXNER AND THE ROCKEFELLER INSTITUTE

In a recent issue of THE SCIENTIFIC MONTHLY, Dr. Walter J. Meek remarked that "Under the able leadership of Dr. Simon Flexner, the Rockefeller Institute for Medical Research has continually exerted a profound influence on American medical science." It seems appropriate that Dr. Gasser's qualities for guiding the work of the institute should be followed with an account of its development under the able leadership of Dr. Flexner. The story of his achievement as director of the Rockefeller Institute for Medical Research is recorded in its progress from a tentative beginning to a position of world eminence. At the time of his appointment as director, in 1903, the belief was general among doctors that medical discoveries could be made only through the efforts of a few gifted, more or less isolated individuals, working under the conditions in which they happened to find themselves.

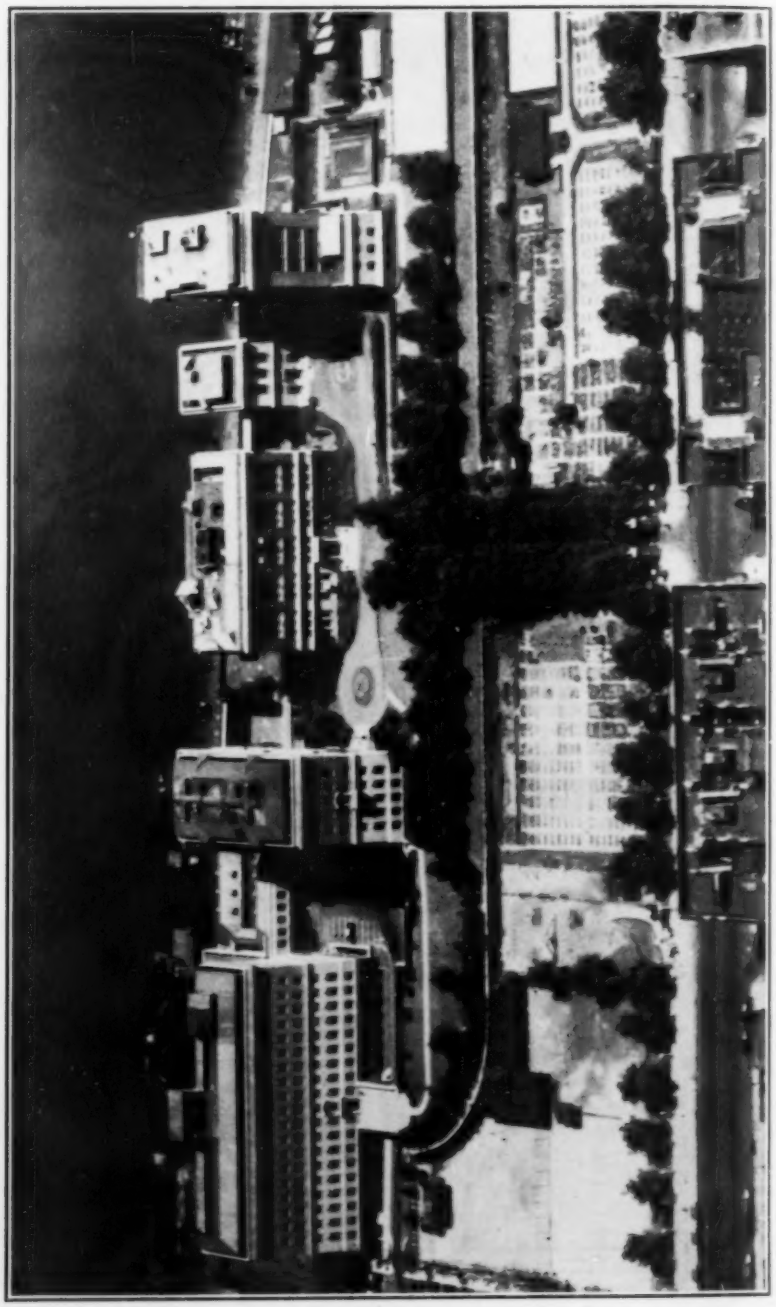
The views of a layman, the late Frederick T. Gates, an associate of John D. Rockefeller, led to the founding of the institute. He became convinced that advances could result from the endowed, purposeful efforts of qualified investigators and he procured Mr. Rockefeller's support for the inauguration of this idea.

The original gift, amounting to $200,000, was not made for the immediate purpose of building an institution for medical research, but was to be used by a group of scientifically trained medical men to ascertain the resources in adequately trained younger men of the universities engaged in the pursuit of medical research. It was to be awarded in grants and fellowships and expended within a period of ten years. During this period, and in this way, it was hoped that more precise knowledge would be obtained concerning the advisability of establishing in the United States an independent institute for medical research. This information was secured more quickly than had been anticipated, so that early in 1902 the conception of a research laboratory to be located in New York City had taken form in the minds of the scientific directors, and met with Mr. Rockefeller's approval.

An advisory board of distinguished physicians was assembled, with William H. Welch as chairman, and they invited Dr. Flexner to direct the new enterprise. He was then forty years old, the recently appointed professor of pathology at the University of Pennsylvania and well launched upon an academic career. Nevertheless he accepted, and under his direction investigations were begun on the problems of disease, by a handful of workers in a dwelling house converted into laboratories.

Dr. Flexner had already completed much significant research of his own, at Pennsylvania and the Johns Hopkins Hospital in Baltimore, where he had studied with Dr. Welch. He had taught in both places, had journeyed to the Philippines as member of a commission to investigate diseases there, and he knew the ways of scientists as well as of science. Realizing that genius is always rarer than the material for it to work upon, he saw that the Rockefeller Institute would prove most effective if men were chosen prior to problems. One could trust to opportunity for these.

Among the men he chose were a young Japanese, Hideyo Noguchi, who was later to become a famous bacteriologist and to die of the yellow fever that he sought to understand, and Samuel J. Meltzer, whose singular promise as a



AN AERIAL VIEW OF THE ROCKEFELLER INSTITUTE FOR MEDICAL RESEARCH

THE ROCKEFELLER INSTITUTE SHOWING THE EAST RIVER IN THE FOREGROUND

physiologist would never have been fulfilled had he not been rescued from the demands of medical practise by an institute appointment.

Dr. Flexner turned his own efforts to the comprehension of cerebro-spinal meningitis, which was then rife in New York City, and he succeeded in developing a serum that much lessened the mortality from the disease and remains the best available remedy for it to this day. He also, under institute auspices, assumed control of the *Journal of Experimental Medicine*, which had suspended publication, and as editor brought it to its present influential position.

The demonstration of the possibilities of the institute resulted in successive gifts to it from Mr. Rockefeller, ensuring it permanence and a widened scope. The first of its several laboratory buildings was erected in 1906, and in 1909 the hospital of the institute, where selected cases of human disease have been treated and investigated by doctors trained for the purpose and free from all other duties.

During this period infantile paralysis had begun to maim many children. Dr. Flexner and the late Paul Lewis succeeded in transmitting the disease in monkeys so that it could be the better studied. This step resulted in findings of signal importance, notably that the virus causing the paralysis enters and leaves the patient by way of the nose and throat. The disease has since been the main subject of Dr. Flexner's personal research, but he has also studied other

LABORATORIES OF THE ROCKEFELLER INSTITUTE AT PRINCETON

infections of the nervous system and the influence of various conditions on experimental epidemics in "mouse villages"—this always with an eye to the human instance.

The fact is recognized now that the solution of some medical problems may require knowledge as broad as the physical world, that the forces determining crystal structure are responsible for the formation of curious spots on the leaves of plants may have importance for human disease. It was not so plain a fact when Dr. Flexner and his associates on the board invited the eminent biologist, Jacques Loeb, to become a member of the institute. Dr. Loeb utilized in his experiments the simplest forms of life for the discovery of general laws.

The selection of Theobald Smith to head a division for the study of animal diseases, with buildings and grounds at Princeton, New Jersey, was an equally wise choice. Dr. Smith had been the first to show that insects can transmit disease and to distinguish the differing potentialities for ill of the tubercle bacilli of cattle and human beings. Both these noted investigators added largely to science under the favorable conditions provided for them. Recently a division for the study of plant diseases has been added to that for animals at Princeton.

When the institute was first chartered education was set down as one of its purposes. No such organization had existed previously, though groups of workers had assembled about outstanding men, such as Pasteur and Koch, but others have now been patterned upon it. Within its walls many investigators have been trained to research, and many have become influential in research or teaching, here or abroad.

Dr. Flexner's ability as an investigator has found expression not only in his personal work, in his perception of the potentialities of others, but also in administrative steps whereby new opportunities of discovery have been provided. His success in this relation has been evident in the renown of the institute as an instrument for good, over and above the individual merits of any of its workers. Honors have come to him in great variety. He is a member of the Royal Society of London, a Commander of the Legion of Honor of France and has received the Order of the Sacred Treasure of Japan, as well as honorary degrees from numerous universities.

During the world war Dr. Flexner was a colonel in the Medical Corps, and he has served on numerous commissions dealing with public health.

Dr. Flexner plans to devote himself to the writing of a life of Dr. William H. Welch, who was chairman of the Board of Scientific Directors of the institute from the outset until a year before his death in 1934. In spite of his retirement, Dr. Flexner can not but help be the guiding spirit of the institute for many years to come.

THE PORTABLE RADIO APPARATUS AT HARVARD UNIVERSITY

THE Cruft Laboratory of Harvard University has recently constructed an experimental car to be used in a variety of new radio investigations. Experimental trucks have often been used by broadcasting companies, radio inspectors, police departments and other agencies interested in some special type of engineering application. Ordinarily these trucks have been employed in making surveys of field strength produced by a definite transmitting station, or in relaying special broadcasts to a control station.

The new portable laboratory differs from these previous experimental trucks in purpose and in construction. It is designed to carry on in the field a wide variety of scientific measurements which have hitherto required the facilities of fixed stations and to undertake new types of experiments which could not be performed in ordinary laboratory buildings.

The new developments are based on experience previously obtained by the Cruft Laboratory staff in less extensive field measurements, involving the use of two automobile trailers. More than a year ago echoes of radio signals were recorded automatically on photographic paper at points many miles distant from Harvard University and were compared with echoes received in Cambridge, close to the transmitting station. In this way it was possible to obtain an indication of the movement of individual clouds of electrons, drifting over the earth at a height of approximately 62 miles. The echoes appeared and disappeared several minutes earlier at one station than at the other. The new portable laboratory carries transmitting sets as well as sensitive receiving equipment, and it is now possible to extend the scope and the accuracy of the simultaneous experiments.

The transmitting set is a special type that sends a circularly polarized or "corkscrew" wave, which can be made to spin in a clockwise or counterclockwise direction as it moves through space. The set can also transmit the ordinary type of radio wave. Voice and code modulation are provided for communication with the home laboratory and with other cooperating stations. Two battery-operated high-voltage generators and an alternating-current generator provide full power for all apparatus even when the mobile laboratory is completely isolated, though outside power sources may be substituted when available. A wide choice of wave-lengths is provided.

In certain types of long-distance simultaneous echo experiments a trailer is also used. In this case elaborate crystal-controlled vacuum tube circuits permit extremely accurate synchronization of the receiving apparatus with the transmitter at the home laboratory. This synchronization is accurate to 0.0001 per cent. per hour and is independent of the radio wave and the characteristics of the power line.

The laboratory carries an ultra-high-frequency transmitter, and three associated receivers operating on 5 meters, 2.5 meters, 1.25 meters and on special experimental assignments. These are used in studying the effect of geographical and meteorological conditions.

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THE MOAB MASTODON PICTOGRAPH

Rock carvings, variously known as pictographs or petroglyphs, are familiar features to persons who have worked in the canyon-cut country of the Southwest. That they have not excited greater interest is perhaps due to the fact that they commonly portray such things as aboriginal man was doubtless familiar with; goats, serpents, human figures and fowls make up most of those I have personally examined. In 1924, however, I was informed by John Bristol, of Moab, Utah, that there was what he believed to be a mastodon pictograph some three miles down the Colorado Canyon from that village. Though this excited my interest, the search had to wait for ten years until I was again in that vicinity last summer. In August of last year, Dennis Baldwin, Fred Strong, Jr., and I, after considerable searching, found the desired pictograph.

That this carving is designed to be an elephant or mastodon is evident. It represents a good deal of work on the part of the primitive artist, for the figure, from the end of his very "pachydermous" tail to the tip of his trunk, is almost two feet long and appears to have been made by a painstaking method of chipping the whole figure from the solid rock wall with a blunt pick, chisel or similar tool. It is a recessed or etched figure, composed of closely spaced "pock marks."

Such figures do not stand out in sharp contrast against their dull red sandstone walls, and one might pass within a few feet of even so large a one as this, time after time, without seeing it. Chalk was carefully rubbed over the pitted surface in order to make photographs.

That this pictograph is genuine seems entirely plausible to me, else the hundreds of similarly etched figures of goats and other creatures are not.

In the first place, the technique of the various pictographs which I examined show a decided uniformity of method of execution; all the larger figures have been chipped from the rock walls with some blunt pick or awl-like tool.

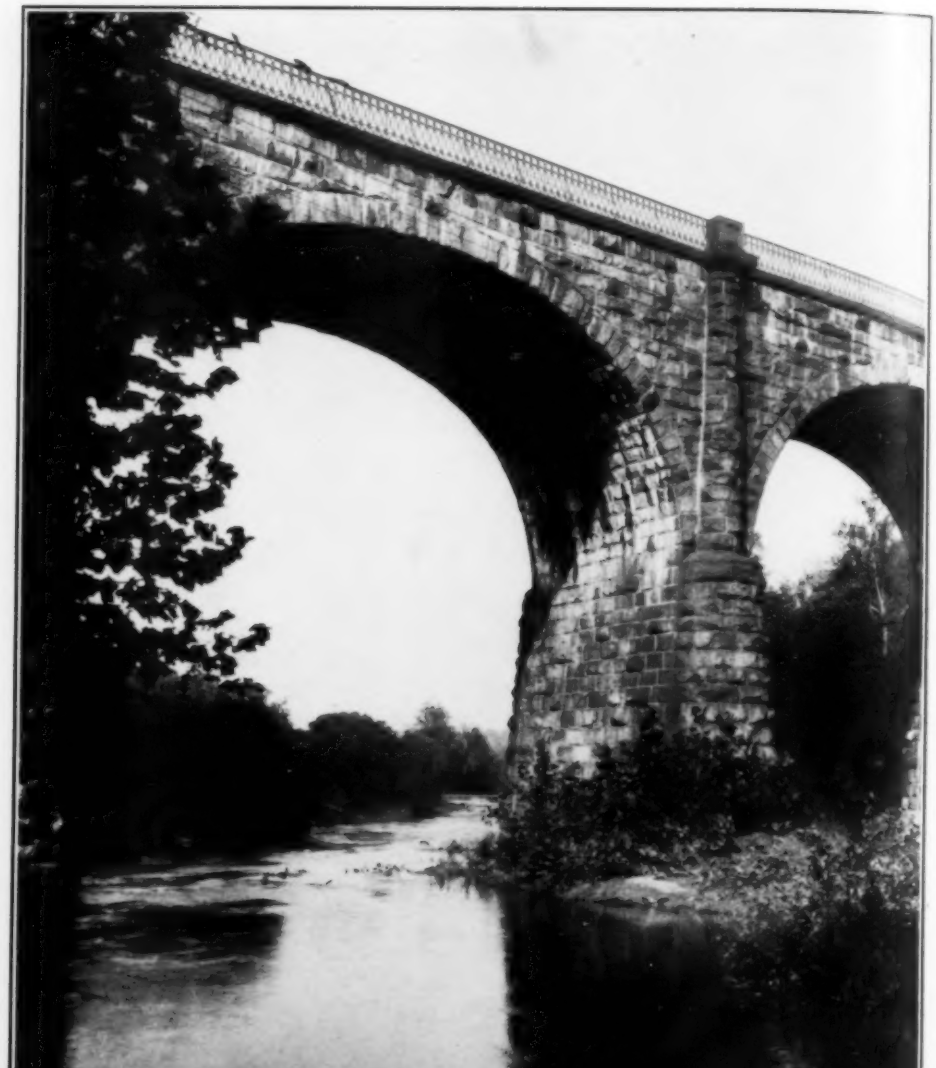
In the second place our "mastodon" occupies an inconspicuous place; it is back from the river about two hundred yards and well above a rugged rock ledge at least fifty feet high. Men might pass it by, as they appear to have done, for years without seeing it, for it is not near any path or route which any one would normally take in going up or down the river. Were it the work of some itinerant cowboy or other person wishing to establish a hoax it does not seem that he would have deliberately placed the figure in a position where the likelihood of its discovery would be so remote. Nor does it seem any more reasonable that an insincere artist or worker would devote so much time and energy to such a project, as is necessarily involved in the execution of this figure.

Thirdly, a curious kind of "vandalism" has prompted many persons to scratch their initials and even stupid inscriptions across some of the more accessible and better-known pictographs. I saw one set of initials bearing the date of 1896 beside some goat pictographs. The latter lacked the freshness of the initials, indicating that they are probably not recent in the sense that the initials are. It would be pure folly,

SOME COMMON KINDS OF PICTOGRAPHS

however, to hazard a guess as to their actual age, for it would be most difficult to estimate the rate of weathering of such rock carvings in the partially protected places they occupy on the canyon walls. There does not, however, seem to be any good reason for supposing that such figures as the one here described possess any special antiquity. Its chief interest lies not in its actual age, but in the fact that it appears to be an authentic link between aboriginal man and the elephant or mastodon, for it is highly improbable that any primitive artist could have achieved so good a likeness without having seen such a creature or having at least seen a picture of one done by some fellow artist.

THE MASTODON PICTOGRAPH



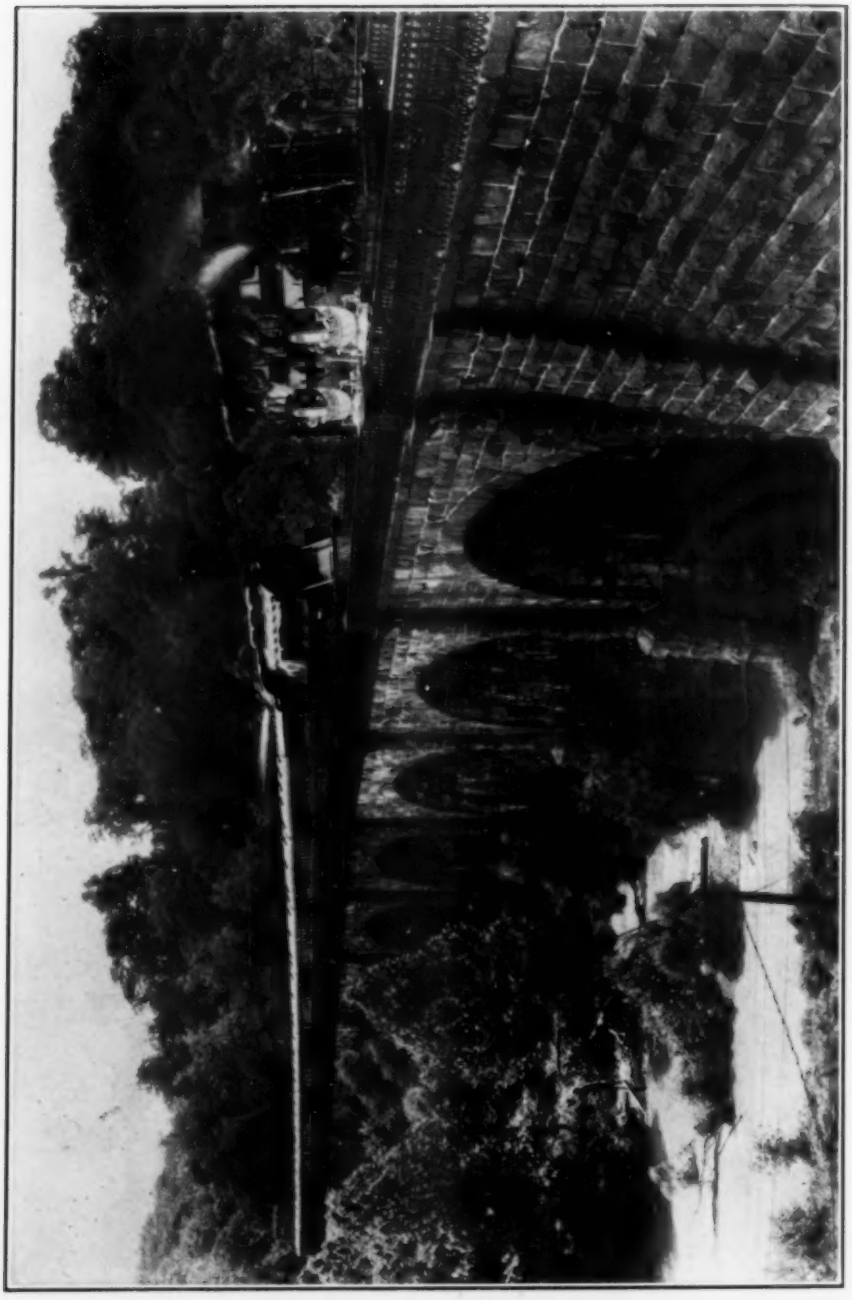
THE OLDEST STONE-ARCH RAILROAD BRIDGE IN THE WORLD: THE THOMAS VIADUCT ACROSS THE PATAPSCO RIVER

On July 4, 1835, a railroad president and his group of directors watched a little "grasshopper" locomotive steam its way across a new stone bridge. That bridge was the Thomas Viaduct. It spanned the Patapsco River between Relay and Elk Ridge Landing, Maryland, and this was its dedication day; after one hundred years, this viaduct seems destined forever to remain the faithful servant of the railroad. Trains of all sizes and weights have stood still upon it, crawled over it and flashed across it, but never a stone falls, never an arch quakes. The railroad was the Baltimore and Ohio, America's first, and Philip Thomas, its first president. Soon the last shipment of rail iron would arrive from England and then the first railroad would nose its way into the heart of the nation's capital. The weightiest problem of the building of the Baltimore-Washington branch of the railroad had been solved.

For five years the railroad had been carrying passengers and freight on the "Old Main Line" between Baltimore and Ellicott's Mills *via* Relay, the halfway station. Relays of horses were stationed here to provide fresh "motive power" for the railroad in its earliest days. Hence the name. Here, too, the railroad had to veer to the west—for the Patapsco stopped its course south toward Washington. It was near here that Peter Cooper in the summer of 1830 had driven his little Tom Thumb locomotive in the famous race with the coach horse. He lost the race, but settled for all time the practicability of steam as motive power for railroad trains. For four years now steam engines had been hauling the trains. The "York," the first practical locomotive, had been followed by the "Atlantic," "Arabian," "Traveller" and several lesser lights. And now there were four new ones—all of the same old "grasshopper" type with vertical boilers, and named for the first four presidents of the United States. These were all set to steam into Washington. The line now was open as far as Bladensburg. Orders had been issued, and within a few days service on the Washington Branch would begin, with stage coaches meeting the trains at Bladensburg and completing the journey to the city.

Designed by Benjamin H. Latrobe, Baltimore architect, the building of the Thomas Viaduct was executed by John McCartney, of Ohio, under the direction of Jonathan Knight, principal assistant engineer of the railroad, and Caspar W. Wever, superintendent of construction. The material was native granite. In the 1840's the viaduct was found to stand up well under a locomotive pulling thirty loaded freight cars—a total weight of 113 tons. A century later we find the same viaduct—with no change in its construction since it was built—bearing with ease the heaviest engines, some weighing upwards of 350 tons. Engineers estimate that it will be able to bear the weight of heavy trains for hundreds of years to come.

The span consists of eight elliptical arches, constructed of native granite, with clear openings that vary in length from 57 feet 10½ inches to 58 feet 4½ inches. Its total length is 612 feet; height, 60 feet; width, 26 feet. It is built on a four-degree curve. The depth of its foundation is not known. Its pier sides are on radial lines, forming arches. Each pier is 9 feet by 26 feet. The structure contains 24,476 cubic yards of



THE OLDEST STONE-ARCH RAILROAD VIADUCT IN THE WORLD

THIS BRIDGE COMPLETED ITS FIRST CENTURY OF CONSTANT USE IN JULY WITHOUT CHANGING A STONE. THE 103-YEAR-OLD ATLANTIC LOCOMOTIVE AND IMLAY COACHES IN VOGUE IN THE 1830'S ARE CONTRASTED WITH THE NEW STREAMLINED TRAIN—THE ROYAL BLUE—THAT BEGAN USING THE BRIDGE EARLY IN THE SUMMER ON THE WASHINGTON-NEW YORK ROUTE.

masonry and cost $142,236.51, or $5.80 per cubic yard of masonry. It would be difficult to duplicate the structure to-day, since there are no longer any stonemasons who do that sort of work; and even if there were, it could not be duplicated for less than a million dollars. The original structure was made wide enough to accommodate double tracks. It is the oldest stone-arch railroad viaduct in the world.

When the last stone had been placed and the finishing touches added, McCartney, wishing to perpetuate his own name in connection with this masterpiece of construction, erected at his own expense a monument, which is shown to the right in the reproduction of the drawing on stone. On it he had inscribed the names of the directors of the railroad, the directors of the state of Maryland and those of the city of Baltimore, the names of the architect and others connected with the building of the viaduct, and his own name, "John McCartney of Ohio," in two places.

On August 25, 1835, the first official run was made by trains from Baltimore, across the viaduct and into the heart of Washington. The curve of the viaduct made it possible for passengers to view portions of it and to comment upon it as the trains crossed it. One writer of the day called it "one of the noblest bridges ever spanned." Another termed it a "most beautiful work of art." Still another declared that he wept tears of joy at the thought of living in an age that presented such a magnificent view. At that time it was the largest stone bridge in the country. Until after the Civil War this was the only railroad into Washington, and over this viaduct passed all the troops and supplies of the Federal Army. The span was heavily guarded.

The old Relay House, located in a charming spot on the east bank of the river, was a famous old hostelry. During the days of early railroading all trains stopped here to changes horses. Later they changed cars—not because this was necessary from an operating standpoint, but because it was thought it would be nice to have passengers continue their journey in a fresh, clean coach. Relay House was for years an eating place for train passengers. When the new Relay House was built, in the seventies, the main building, like its predecessor, was made as a hotel and passenger station in one. It became widely known as a summer resort and was visited by several presidents of the United States. M. T. S.

THE THOMAS VIADUCT
A DRAWING ON STONE BY THOMAS CAMPBELL, DATED JULY, 1855.

THAT BEGAN USING THE BRIDGE EARLY IN THE SUMMER ON THE WASHINGTON-NEW YORK ROUTE.

GASOLINE FROM COAL

THE famous German I. G. chemical works of Oppau-Ludwigshafen have completed a three months' trial run with a continuous process for making gasoline from coal, according to Science Service. A thousand kilos (450 pounds) of coal yielded 600 kilos (270 pounds) of gasoline of good anti-knock quality. Using the Bergius process of hydrogenation, powdered coal and heavy oil are mixed in a chamber with catalysts under a pressure of three hundred atmospheres and 460 degrees centigrade temperature.

Pressed by the lack of petroleum products within its boundaries and the lack of colonies which might produce petroleum, Germany for years has continued gasoline-from-coal research. The present trial run is one of the largest ever completed. And Great Britain, just across the North Sea, has gone into the field, not because its colonies do not yield oil for gasoline, but to encourage the industry in event of war. The British Navy buys large amounts of British gasoline made from coal and low-grade oils at high prices to subsidize the industry and keep it going.

Gasoline from coal and low-grade oils is technically possible but hardly profitable in America. It costs at least three times as much at the factory for a gallon of coal-made gasoline as for a gallon of the current American gasoline now on sale here. With the warning of the U. S. Geological Survey that present petroleum reserves, if used at present rates, will last only another thirteen years, government scientists suggest, at every opportunity, that the United States should enter into a study of coal gasoline. The U. S. Bureau of Mines, while not doing this type of research at present, has the problem near the top of its list and will undertake investigations when very modest funds are appropriated.

From the American standpoint the main problem still to be solved is the optimum conditions for using American coals, which differ decidedly from European coals. Already American oil companies have devised processes whereby low grade petroleum can be turned into superior gasoline. The next step would be to use the tarry products from petroleum distillations for the same purpose. And finally would come the use of coal dust itself.

While America has not the immediate economic pressure for starting coal dust gasoline research, a decade hence the situation will be different. Government scientists, foreseeing this day, are anxious to get at the preliminary work so that when the time comes they can present a whole program to relieve the problem. At present what work has been done in the United States has been mainly in university laboratories, so much so in fact that the problem is principally of academic interest.